

**TEACHING CHEMISTRY OF WATER PURIFICATION IN GRADE 11 USING  
LOCALLY AVAILABLE MATERIALS THROUGH THE SCIENTIFIC INQUIRY  
APPROACH.**

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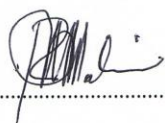
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# **DECLARATION**

I declare that **TEACHING CHEMISTRY OF WATER PURIFICATION IN GRADE 11 USING LOCALLY AVAILABLE MATERIALS THROUGH THE SCIENTIFIC INQUIRY APPROACH** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.



SIGNATURE

(ROBERT DAVISON MAKONI)



DATE

## **DEDICATION**

This dissertation is dedicated to my late mother, Fiona Rudo Chagaresango who, upon her demise when I was eleven years old, impressed upon me that education is the key to a holistic approach to solving many a challenge experienced in life.

## ACKNOWLEDGEMENTS

By the grace of the Lord, may more blessings be added unto all who help others see and live in the light. Praise and glory to the Almighty God for giving me the strength, courage and wisdom to persevere in my studies.

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## ABSTRACT

This dissertation surveyed the validities of teaching the chemistry of water purification in South African schools using locally available materials (LAM) through the scientific inquiry (SI) approach. The researcher randomly selected four secondary schools that provided a small and purposive study sample of thirty-two Grade 11 learners and four teachers. The research design applied a mixed-method approach, consisting of qualitative and quantitative methods of data collection. Within this approach, the outcome of SI instruction that integrated LAM was compared with that of conventional instruction through a quasi-experimental control groups design. The researcher identified in the analysis of interviews and questionnaires the most complex aspects of the chemistry of water purification for learners to understand as redox reactions, acid-base systems, precipitations, and chlorination. However, the use of LAM through the scientific inquiry approach made it easier for learners to understand the concepts.

The high mean scores ( $\bar{X}=80.88$ ;  $SD=10.28$ ) in Research-based Test 2 (RBT2), of the experimental groups taught through SI signified that those learners immensely benefited from an active and collaborative learning environment. The lowly scores ( $\bar{X}=61.69$ ;  $SD=4.21$ ) of control groups could be attributed to a linear and passive participation of learners in the conventional classroom instruction. The marks of the two groups in post-test RBT2 were paired and contrasted using GraphPad software. The results showed that  $t=6.699$ ,  $df=21$  with a significant value of 0.0001, which is less than 0.05 ( $p<0.05$ ), hence it can be inferred that the difference between the means of the two groups was not only statistically important but also worth an explanation. The higher performance scores in RBT2 and the Rubric Assessment Tool (RAT) in experimental groups represents that the intervention was successful in the implementation of instructional design in the the study. In addition, the learners had mastered the crucial aptitudes that included self-discipline in understanding, cooperative learning, searching relevant text on topic, hands-on or laboratory practice and logical thinking in problem solving by working through the SI activities that used LAM.

**Keywords:** Chemistry Education, Constructivist Theory, Locally Available Materials, Research-based Tests (RBT), Rubric Assessment Tool, Scientific Inquiry, Water Purification

## ACRONMYS

ANOVA	Analysis of Variance
CAPS	Curriculum Assessment Policy Statement
CASS	Continuous Assessment
DoE	Department of Education
DWAF	Department of Water and Forestry
ID	Identity
ISD	Instructional Systems Design
IUPAC	International Union of Pure and Applied Chemistry
IYC	The Global Experiment of the International Year of Chemistry
LAM	Locally Available Materials
NCS	National Curriculum Statement
NRC	National Research Council
NSES	National Science Education Standards
RAT	Rubric Assessment Tool
RBT	Research-Based Tests
SAWYP	South Africa Water Youth Price
SI	Scientific Inquiry
<i>t</i> -test	Student Statistical Test
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WEP	Water Education Programme
WHO	World Health Organisation

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## CHAPTER 1: INTRODUCTION

### 1.1 Contextual background to the study

Chemistry as a subject content is defined as a precise body of knowledge that is related to the structure of matter, materials and chemical reactions. Schwab (1960) reasons that science is not only defined as a pile of subject material, but can also be distinguished as an active process of investigation that should be imparted to learners as a philosophy of ideas and realised in application and understanding of these ideas in the environment (NSES:NRC, 2000). Based on Dewey's definitions, the National Science Education Standards (NSES) and other scholars often describe science as content knowledge and a procedure, and that reflects his [Dewey] ideas about scientific thinking. He views the scientific procedure as an instrument for inquiry that is general in nature (Connell, 1994). Grade11 learners who participated in this study were not concerned about understanding the difficult nature of scientific inquiry method, but were involved in a scientific inquiry (SI) process that integrated locally available materials (LAM), and led them to understand concepts of water purification easily.

According to Talanquer (2011), three major aspects of the chemistry education that are appropriate for instruction are: experiences that include physical knowledge, models that represent concept, and underpin explanations of chemical phenomena, and visualisations that comprise visible representations, and enable interaction by means of symbols and chemical formulae etc. These symbols link both concepts (experiences) and thoughts (models) about a chemical phenomenon. Johnstone (1984, 1991) asserts that chemistry is a complex subject to understand because of the thought of its conceptual depiction at macroscopic (descriptive), microscopic (explanatory), or representational (symbolic) levels. This dissertation was concerned with using locally available materials (LAM) to deal with the difficulties encountered by Grade 11 learners in understanding the chemistry of water purification in classroom instruction. According to Johnstone (1980) learners' approaches to understanding of science ideally conflicts with the world of science as an active body of knowledge, and this also impacts on the conventional instruction that teachers have been applying in classrooms. However, Johnstone (1982) argues that the learner cannot simultaneously master all three representations of chemistry in a classroom instruction. Reid (2000) submits that instruction of chemistry courses in schools should be characterised by demands of the learner and not by

the philosophy of subject, and Johnstone's (2000) supplementary publication underscores that the sequence and instruction of a school subject should mirror the learner's behaviours of learning. This implies that instructional and learning material should express the demands of the learner, and describe the sequence of instruction within the cognitive levels of the learner. According to McCormick and Li (2006) learners experience problems in learning chemistry is because of learning strategies and learners' thoughts of chemistry as subject. In order to address these instructional challenges and in search of innovative instruction, a number of teachers have applauded the practice of science inquiry in school laboratory tasks (e.g. Abd-El-Khalick, BouJaoude, Dusehl, et al. 2004; National Research Council, 2000). The learning of chemistry of water purification by Grade 11 learners who participated in this study was facilitated by the SI instruction that used LAM such as sand, sand silt, and gravel, crushed pieces of glass for filtration, charred vegetation or charred bones for adsorption of chemical impurities and bleach for chlorination to kill pathogenic organisms in water. Grey water is any household wastewater contaminated with organic and inorganic impurities from kitchen sinks, dishwashers, bathroom sinks and tubs and showers. Removal of impurities from grey water may involve chemical, physical, mechanical, and biological, methods or combination of two or more of these methods. For the purpose of this study, five basic steps of water purification are as follows: *aeration*, which involves hydration and hydrolysis of impure gases; *coagulation and sedimentation*, which result in precipitation of higher oxidation metal ions; *filtration* of solid particles by sand filters; and *disinfection* of pathogenic organisms by pH dependent equilibrium chlorination of water. The topic "Water Purification" presents an authentic scientific problem and is a notable departure from the traditional research studies on structured topics. Many chemistry concepts, particularly in water purification, those Grade 11 learners who participated in this study found difficult to understand are fundamental to chemistry knowledge and are interrelated. Many scholars maintain that the source of misunderstanding of chemistry by many learners is a result of the continuous interlink between thoughts of the empirical (physical) knowledge and theoretical representations of chemistry. Many learners experience problems understanding certain concepts of chemistry, for example chemical reactions that occur in solutions (Çalık, Ayas & Ebenezer, 2005, Çalık, Ayas, & Coll 2006; Pınarbaş, & Canpolat, 2003), thoughts of intellectual simulations (Coll & Taylor, 2002; Coll & Treagust, 2001a, 2003; Taber, 2002), the quantitative stoichiometry or molarity of solution chemistry (Gilbert & Watts, 1983), concepts about balancing redox equations and stereochemistry (Zoller, 1990 ) the attitude on chemical reactions and



reactivity (Zoller,1990; Abraham, Grzybowski, Renner & Marek, 1992), and misconceptions about acids and bases (Dermircioglu, Ozmen & Ayas, 2004). As for the topic chemistry of water purification, prior to SI instruction, many participant learners found it hard to link chemical formulae (visualisations) to their empirical knowledge (experiences) and theoretical (models) representations particularly in solution chemistry of the topic that comprise redox reactions, acid-base systems, pH dependent precipitations, chemical equilibria and stoichiometry or molarity in chlorination.

Table 1 (Department of Education (DoE), 2011, p.p.43–73) evidently displays the unsatisfactory performance of Grade 12 learners' results in the Physical Sciences in South Africa, at national level and, worse still, in the Limpopo province, Vhembe District and the Circuit A in which this study was based.

**Table 1: South Africa: Analysis of 2009 and 2010 learners' marks in Physical Sciences**

<b>Subject pass rate</b>	<b>2009</b>	<b>2010</b>
<b>National</b>	36.8%	47.8%
<b>Limpopo Province</b>	31.8%	16.1%
<b>Vhembe District</b>	40.6%	52.8%
<b>Circuit A</b>	30%	44%

That the DoE (2011) qualifies a final score of at least 30% as pass rate that includes Continuous Assessment (CASS) tasks for Physical Sciences in South Africa is indeed a mockery of the education system, and that renders curriculum organisation and practice to appear sceptical and suspicious. In fact, this is a bad picture of the waning pedagogy as far as instructional design and methods are concerned; in particular of concern is the disconnection between theories, laboratory practices and applications of Physical Sciences in the environment. Umalusi's (2010, p.39) found that most learners scored low marks in questions of high cognitive level that needed systematic reasoning to solve the problems, as opposed to high marks scored in questions of low cognitive level that examined simple understanding in subject content. For example all learners in Physical Sciences Paper 2 (chemistry) performed poorly in solution chemistry involving the chemical equilibrium constant ( $K_C$ ), (Umalusi,

2010, p.79). Many learners are reported to have experienced problems in answering analytical or inquiry-based questions that linked concepts, experiments and application of chemical reactivity and chemical change, balancing chemical equations and redox reactions (as redox potentials) (Umalusi, 2011, p. 46; 2012, p.339). The findings of Umalusi indicate that most learners obtained high marks from simple experiments and research projects that were of low cognitive level. A marking scheme proved a reliable instrument in assessing the control test, but not so for the practical tasks that presented significant differences, as teachers wrongly applied some marking rubric for any prescribed task (2011, p.47). This finding implies that many teachers appear to struggle, have insufficient, or lack of knowledge and skills training to design, develop and apply their own rubric for assessment for a specific practical task. In the main many teachers have a tendency to use a generic rubric that could be obsolete for a set practical investigation.

These findings were similar to the DoE's (2012) Malamulele Central Circuit School A's report on the analysis of the November /December 2012, Grade 11 Physical Sciences, Paper 2 results that noted, " A majority of learners scored higher marks in CASS tasks than in final examination. Of particular concern was that marks for practical tasks including experiments and research projects were exceptionally higher, and there was evidence in the learners' scripts that they copied each other." School A was one of the six schools that participated in the study. One teacher at the school described the "low quality of the practical tasks that are set by the DoE, as science for fiction appropriate for kindergarten kids." The report further noted, "Learners do not learn meaningfully in practical tasks that are also deemed irrelevant to the chemistry theory, and not linked to practice in the laboratory and application in the environment." The analysis report of school A, also identified the chemistry concepts that learners failed to grasp in Grade 11, Paper 2, as redox systems, acid-base systems, molarity, balancing redox and chemical equations, chemical reactivity and chemical change and a link between theory and practical tasks that formed the bulk of the topic water purification. Based on this evidence of learners' poor performance in examinations, research topics such as water purification had been a problem to those learners at school A, because teachers did not teach them sufficiently in the school laboratory practice. In a related analysis in biology Umalusi (2011, p.83), found that all investigative type of problems in examinations and tests were difficult for many learners. They [learners] were often apt to write general responses to these problems. This scenario is a reflection of incompetency in conducting practical work at

schools. These learners' problems of misunderstanding of a link between concepts taught in the classroom and experiences in the laboratory prompted the researcher to investigate the effects of teaching chemistry of water purification via SI using LAM in schools in Malamulele Central Circuit, in the Vhembe District of Limpopo Province in South Africa.

According to Macfarlane (2014), Umalusi report that the many learners, particularly from poor socio-economic circumstances continue to underperform in Physical Sciences. Malamulele Central Circuit where this study was conducted comprise schools that were historically neglected regarding equal access to education particularly in the provision of practical infrastructures that are needed to carry out science inquiry activities. In addition, for many of these Grade 11 learners this kind of learning was unique to them since they had been expected to produce and present their knowledge in authentic scientific formats such as research reports and posters. Learners needed to have performed rigorous scientific inquiry processes just like scientists. Chinn and Malhotra (2002) observe that only very few schools offer science courses that include scientific inquiry, worse still even those schools that have properly designed and advanced syllabi usually end up reduced to guided lessons with few practical tasks (Fishman & Krajcik, 2003; Schneider, Krajcik & Blumenfeld, 2005). Latour and Woolgar (1986) argue that laboratory practices turn out to be relevant only when they are interpreted as symbols and signs that represent every step as a visible effect, more so in scientist laboratories. Based on this analysis, science as a way of thinking is learnt meaningfully when concept is taught at visual and representational levels. The learners in this study were expected to undergo the arduous scientific research process that comprised a range of steps with each producing a visible effect. In South Africa, the Physical Sciences curriculum includes two control tests, mid-year examinations, two experiments and one learner-based research study set by the DoE. These external assessment tasks constitute Continuous Assessment (CASS) tasks in the school year for Grades 10 to 12, and add 25% to the final mark. The final examination comprises 75% of the final assessment mark. Learners' research study somewhat weighs in 25% of CASS. Water purification is an integrated and context-based topic comprising mainly Grade 11 chemistry concepts such as redox reactions, precipitations, and acid-base systems that are systematically covered over two years from Grade 10 to Grade 11. In Grade 10, these concepts are taught as basic elements of water chemistry, for example the physico-chemical aspects of water and the water cycle, while in Grade 11 they are taught as abstract chemistry concepts broadly related to different chemical

reactions in the process of water purification. Therefore, if the research topic is well conducted using LAM, it will complement the final examination as well as assist learners to master chemistry that is relevant to real life situations. The constant interface between theory, practice in the laboratory and application in the environment will facilitate understanding concept of the topic by learners.

### **1.1.1 Rationale for the topic: Water Purification**

Neither the present Curriculum Assessment Policy Statement (CAPS) nor its predecessor the National Curriculum Statement (NCS) documents of South Africa offer some methodological provision to incorporate theory, practice in the laboratory and application in the environment, thus the instruction of chemistry of water purification often continues on a platform that opposes the projected goals. The Curriculum Planning and Development Division (CPDD), (2007) of the Singapore Ministry of Education claims that inquiry in science is integrated into the science syllabus in several schools at district level in the United States of America (USA), and outstandingly in each and every one school in Singapore. However, Eltinge and Roberts (1993) report that in the USA at state and district level most of these science syllabi were not connected to science inquiry, but instead were concerned with the subject matter. In the NCS and CAPS documents for Grade 10 and Grade 11, the chemistry of water purification is not clear or explained in depth as far as its curriculum implementation is concerned with regard to the integration of theory, practical tasks and application. In other words, the chemistry concepts of the broad topic are not presented in the sequential curriculum, but unfold over several topics of chemistry in curricula and textbooks. In Grade 10, learners are taught basic aquatic chemistry, mainly the physico-chemical features of water and the water cycle, while in Grade 11 more complex concepts related to the topic are taught, such as the acid-base system, pH dependent chemical equilibria, solution chemistry which involves dissociations, hydration and hydrolysis, and quantitative stoichiometry (molarity) of chlorination of water during water purification. In respect of pedagogy, syllabus encourages practical and mixed content approach of learning in schools; however, in routine classroom practice teachers mostly use schoolbooks (Heinonen, 2005; Perkkilä & Lehtelä, 2007). In this study, chemistry of water purification is perceived an authentic problem because the many different concepts it offers direct learners to master chemistry from multiple perspectives approaches of learning, in particular through SI that integrates LAM, and this links well to the everyday life experiences of learners. For example, in the CAPS document, under chemical systems,

learners learn how the hydrosphere interacts with other global systems and the very important function that water has on our planet as well as threats to the hydrosphere. Learners are also encouraged to engage in proposed discussions on creative water conservation and investigations, for example building dams and testing the contaminants and quality of water samples. The teacher has to provide guidance, particularly in learners' research projects on water purification. For this reason, the researcher chose the topic water purification for the present study in order to implement a dynamic and integrated school learning topic that links theory, practice in the laboratory and application in the environment.

The Department of Water Affairs and Forestry (DWAF) (2010) in collaboration with the DoE have made efforts to promote Water Education Programme (WEP) in South African schools. WEP has now become part of the formal pedagogical syllabus that represents learners' everyday practices in the environment. Further to that the Global Experiment of the International Year of Chemistry<sup>1</sup>, IYC (2011) assists learners from all grades in many countries to understand the significance of chemistry by means of practical investigations in aspects of water contamination and clarification. The IYC is a novelty of the International Union of Pure and Applied Chemistry (IUPAC) and the Committee on Chemistry Education and the United Nations Educational, Scientific and Cultural Organisation (UNESCO). The IYC's classroom activities and DWAF's WEP chemistry projects are similar in that they all comprise experiments on water contaminants and purification, which should be conducted by learners in the school laboratory under guidance of the teacher. Teachers can incorporate the water activities into a classroom practice in line with the NCS or CAPS research projects. In respect of this study, these practical activities include a range of experiences that are essential to scientific inquiry processes particularly empirical, investigative and evidence collection skills, and these skills are important in enhancing learners' conceptual understanding of water purification. The limited amount of drinking water available for human consumption makes knowledge about water purification essential for learners in rural communities. This topic makes a positive contribution to the established related research in this field as global and national efforts in water education have significant implications for learners. This is another reason for the choice of this topic for the present study; it has the potential to support and

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<sup>1</sup> Also available on: <http://water.chemistry2011.org/web/iyc> South Africa is generally an arid country with shortage of drinking water available for human consumption. Therefore, knowledge about water purification at global level is crucial for students, particularly in rural communities.

contribute to the national and international initiative that aims to create young scientists who are equipped with exceptional research skills and who are capable of solving authentic scientific problems within real world contexts.

Ramadas (2001) asserts that generally science instruction in developing countries, excludes the significance that lies in creativity of hands-on activities, planning and application of those activities in real life contexts. The research topic is an authentic scientific problem that provides learners with the opportunity to demonstrate the following four different forms of knowledge that define SI as contextualised by Hanauer (2007): physical knowledge (laboratory skills), representational knowledge (writing skills), cognitive knowledge (chemistry of water purification including argumentation skills) and presentational knowledge (conceptualisation of water chemistry).

Havu-Nuutinen, Kärkkäinen and Keinonen (2011) claim that learners' experiences, perspectives and comprehensions of water have not been analysed extensively worldwide despite water being incorporated into the school science syllabi. Recent research indicates that learners do not appreciate the uniqueness of water in life (Ben-Zvi Assaraf & Orion, 2005). For example, Shepardson, Wee, Priddy et al. (2007) observe that learners fail to realise the relevance of water related concepts because these are not methodologically included in school syllabi, but are in fact aligned to certain sequential topics. Furthermore, many scholars concentrate more on specific aspects of water than on application of those concepts in the environment. It was also against this background that the chemistry of water purification was elected as the focus of this study because it aims for a broader discourse of water from multiple perspectives within the paradigm of real life experiences. Previous research has shown that learners' understanding of water concept in the classroom mainly focus on investigating specific learners' perspectives of water concept and distinguishing those physico-chemical and environmental concepts of water, such as floating and sinking (Kawasaki & Herrenkohl, 2004; Havu-Nuutinen, 2005), boiling, evaporation and condensation (Tytler, 2000; Varelas, Pappas & Rife, 2006), the water cycle (Ben-zvi-Assarf & Orion, 2005; Márquez, Izquierdo, & Espinet, 2006), or generally the wetland (watershed) (Shepardson, Harbor, & Wee, 2005; Patterson & Harbor, 2005; Shepardson, Wee, Priddy, Schellenberger & Harbor, 2007). Findings of these scholars revealed that people regardless of age lack holistic knowledge regarding the perception of water and the water cycle, and hold several preconceived ideas and alternative visualisations about it. According to recent studies

by Shepardson et al. (2007) learners failed to explain why humankind was a component of the wetland ecosystem and to describe how human practices could destroy the ecosystem and cause water contamination. Water related topics are difficult for many learners to understand because of the integrative nature of water concepts and the invisible or abstract particulate world of water.

Datta and Osaka (2005) and Meyer (2005) have observed that every science learner, irrespective of their specialisation in specific disciplines should master chemistry knowledge that is relevant and applicable in the environment. The topic “Water Purification” presents water in different thoughts and provides opportunities for learners to think and reason chemistry that links theory and practice in the laboratory and applications in the environment through observation of the different chemical reactions occurring at each stage of the process. In this regard, water purification as part of environmental chemistry has numerous applications. For example, learners could carry out qualitative laboratory tests of municipal water, conduct water audits, protect wetlands and monitor their biodiversity and work like scientists by carrying out innovative research projects on water purification (DWAF, 2010; IYC, 2011). However, several learners possess misconceptions regarding water as a universal process, and in turn, those learners experience problems in monitoring and sustaining aquatic ecosystems (Covitt, Gunckel & Anderson, 2009). Based on this observation, context-based water purification taught by SI using LAM in this study has great prospective to help learners to understand the difficult concepts of water purification. A number of teachers have in particular considered the moral matters of science that involves genetically engineered human replicas and environmental concerns in order to enhance learners’ understanding in sciences and to investigate the connection between science and socio-ethics (Sadler, 2004; Zeidler et al. 2002). This study seriously considers the significances of moral values that are associated with pedagogy in teaching water purification using LAM to solve learners’ misunderstandings of chemistry concepts of the topic. Therefore, teaching and learning through research or project work on topics such as water purification offers learners autonomy (independence) to work with LAM those they are acquainted to, and this makes the learning process interesting.

Brody (1993), claims that teachers should use tangible approaches to teaching water concept to enable learners appreciate their real world experiences, and he [Brody] notes that administration that is related to water quality and quantity will be a prime worry for

civilisation. However, as observed by Brody (1993), the interdisciplinary nature of water related concept with other topics in both natural sciences (physics, biology, and chemistry) and social sciences (arts) challenges the teacher understanding of the topic. As suggested by Holbrook (2005), the researcher elected this context-based research topic based on its potential to shift instruction of chemistry from structured topics to an inquiry approach that closely links to learners' real world experiences. The National Standards of Education and Science (NSES) of the National Research Council (NRC) (1996) propose that learners should undergo authentic scientific inquiry in their science lessons so that their tasks can compare with those of proficient scientists (McGinn & Roth, 1999; NRC, 1996, 2000). Chin and Malhotra (2002) note that despite teachers' ambitions to offer students experiences in holistic scientific inquiry, scholars have discovered that schools need time and practical infrastructures to replicate complex investigation work of scientists, and school inquiry tasks often fail to parallel the difficult and practical nature of science. However, many scholars encourage teachers to teach science purposefully and clearly as a body of knowledge and as a philosophy (Abd-El-Khalick & Lederman, 2000; Schwartz & Crawford, 2004). Some scholars thought that instruction of science using inquiry is an efficient approach that builds capacity to enhance the logical reasoning skills of learners (Duschl & Osborne 2002; Wilson, Taylor, Kowalski et al. 2010). In this study, the researcher anticipated that an investigative task in the form of experiments and research project for learners would enhance their understanding of the complexity of an authentic research process. Recent studies have shown that learners' participation in laboratory work promotes learning that is more productive (e.g. Domin 2007; Hofstein & Lunetta 2004). The research findings of Grouws and Cebulla (2000) and Ingvarson, Beavis and Bishop et al. (2004) have divulged that instructional strategies that provide learners with a prospect to conduct practical tasks are linked to attainment of higher learner grades. Cheung (2006) observes that schools often use textbook-based laboratory tasks for chemistry syllabi because of inadequate practical infrastructure for science inquiry, and against this scenario teachers experience problems in acquiring inquiry resources. A number of science teachers merely let their students recite simple textbook-based experiments as a routine practice for laboratories (Chinn & Malhorta, 2002; Volkmann & Abell, 2003). According to Schneider et al. (2005) teachers who trained in education courses that comprise inquiry in science continue to teach learners through traditional approaches in classrooms. Alberts (2000) and Radford (1998) argue that the sad truth of realising teaching and learning using inquiry in science is often because of teachers' incompetence in science



inquiry. According to Crawford (2000) several teachers who attended training clinics in teaching science through inquiry and received direct assistance still maintain that this approach comprise practical tasks, or that conventional settings render instruction of science through inquiry a complicated practice (Barab & Luehmann, 2003). Songer, Lee and Kam (2002) suggest that shortage of practical organisation, regulated time, and lack of knowledge about SI appear to be the obstacles to teachers' attempts to apply science inquiry in schools. Rutherford & Ahlgren (1990) argue that integrated science topics offer critical teaching and learning that extends beyond school boundaries into real world practices. A focus on teaching water purification using LAM could help learners to appreciate the connection between water impurities, LAM and the application of chemistry outside the classroom. It is vital that realistic and dynamic approach to teaching an integrated and context-based topic such as water purification via SI that integrates LAM is embraced if the national pass rate in Physical Sciences is to be realised.

### **1.1.2 Statement of the Problem**

Having taught for 15 years, the researcher observed that there was no continuity in the science theories (curricula concept) taught in the classroom, the practices in the school laboratory and the application of these theories and practices in the local environment. In this study, a major obstacle in the classroom environment was how to teach learners to grasp the connection between water contaminants and the chemical reactions that occur at each stage of water clarification. Based on this observation the main challenge for the teacher was to facilitate learner's understanding of the abstract chemical reactions that occur at each stage of water purification through representations of symbols and formulae. Therefore the major test was assisting teachers in designing and constructing instructional materials that reflected learners' enacted real world experiences, using local materials that they were conversant with, as suggested by Aikenhead and Jegede (2000). The poor performance of learners in Physical Sciences in the Further Education and Training band and Senior School Certificate Examinations in South Africa is to some extent a reflection of teachers' incompetence in content knowledge, inappropriate approaches to teaching and institutionalised curricular planning, materials and implementation that neglect the pragmatic and dynamic aspect of science. Given this background, the researcher explored effective ways of teaching classroom chemistry through SI using LAM in order to solve the observed instructional challenges.

### 1.1.3 Conceptualisation of the Problem

The National Research Council (2006) notes that teachers expect learners gain immensely from laboratory experiences and tasks but in fact, the opposite is true. According to Umalusi's (2011, p.29) quality assurance report for Physical Sciences, Paper 2, chemistry practical tasks examined concept knowledge as opposed to involving learners in authentic scientific experiences and solving practical-based problems. The report added that in Limpopo Province, most experiments and practical investigation tasks (research work) were simple, and in turn, the level of logical reasoning that was required of these learners' tasks was of low quality compared to other provinces. This study was conducted in Vhembe District of Limpopo Province. In the analysis of internal assessment, Umalusi (2012, p.25) notes that marks that were awarded for practical work were exceptionally high when compared with low marks in the control tests and examinations. In these control tasks, learners demonstrated recall of simple knowledge of concept, but were unable to argue, analyse, or support their answers. It can be assumed that there is lack of or absence of inquiry materials and practices in classroom instruction, and those schools that have advanced organisation in science inquiry also continue to apply didactic approach to teaching despite efforts of scholars and teachers to shift instruction to innovative strategies.

An alternative teaching approach, SI, was applied to teach the chemistry of water purification, through a process of research using LAM. The conventional didactic approach overlooks the impact of LAM in science classrooms, recites concepts in schoolbooks and simply validates an established practical procedure and experimental outcomes that include hypotheses. For purpose of pedagogics in this study, LAM such as sand of specific sizes was used to filter out solid contaminants, activated carbon or charred vegetation was used to adsorb contaminants and liquid or powder bleach was used to disinfect water of disease causing organisms.

The abstract aspects of water purification for example redox reactions, acid-base systems, precipitations, chemical and ionic equilibria and molarity, which many Grade 11 learner participants found difficult, are crucial for advanced studies in chemistry as observed by Mammino (2009) and Sirhan (2007). In the light of these learners' problems, it was imperative to research the various teaching approaches that would intrinsically motivate learners' understanding of concepts, and in turn, this would result in higher achievement rates

(Burdge & Daubenmire, 2001). In order to achieve this, the researcher isolated specific problems that learners experience in learning the topic, and constructed a pertinent teaching approach to assist them in routing these problems as suggested by Herron (1996) and Sirhan (2007). The traditional teaching strategy with its emphasis on knowledge transmission and teacher-centred approaches appears to be incomplete in its capacity to simplify the abstract concepts of chemistry. Hofstein and Lunetta (2004) challenge teachers to organise research that is more comprehensive directed at, among others, tangible laboratory practices in schools and similar environments, and learners' theoretical and practical understanding of concept. Burcin and Leman (2013) report that in recent years teachers responded positively to their [Hofstein and Lunetta] recommendations [i.e. for research], and were more motivated to teaching science through inquiry approaches. However, they also became more sceptical about the applicability of textbook-based practical work, and in fact, the rationale, experiences and aims of this approach. According to Dalton (1985), learners should reason for themselves, be creative, construct, and apply multiple techniques to problem solving. The use of effective instructional approaches such as SI can improve learners' argumentation skills during observations of chemical phenomena in inquiry-guided laboratory activities, in this case the chemistry of water purification.

#### **1.1.4 Purpose of the Study**

The main purpose of the study was to investigate whether teaching the chemistry of water purification through the SI approach to Grade 11 learners using LAM would help to improve their understanding of the concepts related to the topic of water purification.

In order to achieve this purpose the researcher:

- identified difficulties experienced by learners regarding chemistry of water purification using LAM in a classroom environment
- developed and evaluated learner engagement in activities on chemistry of water purification for four schools in the Vhembe District
- integrated LAM in the teaching of a research-based topic “Water Purification” to learners in the classroom in order to improve the learning of concepts

- examined the effects of teaching water purification to Grade 11 learners using: (1) LAM through scientific inquiry and (2) through a traditional teaching approach in the classroom.

### **1.1.5 Research Questions**

The main research question was:

1. What are the features of an effective approach to teaching water purification to Grade 11 learners using locally available materials (LAM)?

In order to answer this research question the following sub-questions were posed:

- a) Which parts of the chemistry of water purification present Grade 11 learners with difficulties?
  - b) How can locally available materials (LAM) be incorporated into Grade 11 chemistry instruction to enhance learners' understanding of the stages of water purification?
2. Is there any difference in the performance of learners taught water purification processes using locally available materials (LAM) by Scientific Inquiry (SI) approach and those taught using the traditional teaching approach?

In order to address these questions, the researcher proposed SI approach to teaching the topic using LAM.

### **1.1.6 Significance of the Study**

The DoE (2010) states that the aim of Physical Sciences (Grade 10–12) is to progress scientific and technological knowledge and acquire reasoning skills that can be applied in the environment, in order to appreciate the marvel of science and its link to “technology, society and the environment.” Based on this statement, it was believed that the study would contribute to the knowledge underpinning chemistry education, specifically chemistry of water purification, and assist policy makers in finding long-term answers to the inadequate performance of learners in Physical Sciences.

The output of this dissertation could be useful for:

- teachers of Physical Sciences who will use the new SI guidebooks integrating LAM to advance their proficiencies in Grade 11 chemistry knowledge, specifically in concepts related to the chemistry of water purification.
- learners who will be able to strengthen their chemistry knowledge through innovation and reasoning, since using LAM in class activities of water clarification is expected to catch the learners' interest and lead to an understanding of concept.
- a scientifically nurtured learner who understands and thrives for a hygienic environment and is skilled in solving scientific-socio-ethical matters that are related to, for instance water quality and water purification.
- curriculum developers, textbook writers, publishers and laboratory apparatus/chemical manufacturers. This study could assist them in designing Physical Sciences syllabi that is relevant to real life contexts and that tie in with SI instruction.

## **1.2 Scope and limitations of the Study**

The focus of the study was mainly on Grade 11 Physical Sciences learners. It examined the effects of teaching water purification through SI integrating LAM on learners' understanding of chemistry concepts at secondary school level.

The present study was carried out in Malamulele Central Circuit, in the Vhembe District of Limpopo Province in South Africa. Limpopo Province has six districts. Malamulele Central Circuit is classified as rural and one of the previously deprived circuits in terms of access to quality education. Therefore, small and purposive samples within the proximity of the researcher facilitated the administration of research instruments and promoted the feasibility of the study.

The main concepts that were taught under the topic "Water Purification" were:

- the physico-chemical properties of filter media such as sand, silt, gravel, glass filings etc.
- physical, chemical and biological separation of contaminants in water

- redox reactions involving precipitation in water of metal ions of aluminum and iron into higher oxidation states by alum and lime during processes of coagulation and sedimentation that makes water colourless
- hydration and hydrolysis of impure gases such as HCl and H<sub>2</sub>S and their removal by aeration of sandbags and the oxidation of Fe<sup>2+</sup> and Mn<sup>2+</sup> into higher oxidation states of +3 and +7
- acid-base systems and equilibria systems of chlorination, leading to the destruction of pathogenic organisms
- calculations in molarity or quantitative stoichiometry of contact chlorine required in drinking water.

### **1.3 Conceptual terms used in the study**

#### **1.3.1 Chemistry of water purification**

Water purification involves the removal of contaminants such as solids, bacteria, algae, plants and organic and inorganic compounds by mechanical, physical, biological, or chemical methods. Clarification of water makes it naturally acceptable for human drinking or use in the environment.

#### **1.3.2 Scientific Inquiry**

The National Science Education Standards (NRC, 1996, p. 23) defines scientific inquiry as:

the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which learners develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.

This study describes SI instruction as an approach that provides learners with an active learning environment through activities that comprise in-class discussions specifically the role of LAM in water purification. In this study, guided simple inquiry-based experiments and a project that integrated LAM were assumed to complement the characterisation of SI.

### **1.3.3 Locally Available Materials**

In a paper presented by Eniajeyu (1983) at Calabar, Cross River State, Nigeria, he defines Locally available materials (LAM) as substitute resources that, enable teachers to carry on with their work in the absence or inadequate of some particular traditional teaching resources. These resources should be cheap and of ease access. In this study LAM are specified as local materials and resources that learners are *au fait*, and facilitate the teaching of chemistry of water purification through scientific inquiry (SI) approach.

### **1.4 Methodology of the research**

In order to solve learners' misunderstandings of the underlying concepts of the chemistry of water purification, the researcher taught the experimental groups A and B, the topic guided by an SI approach that applied LAM. The participant teachers taught the control groups C and D by a conventional approach that involved chalkboard activity as well as in-class dialogic discourse of the topic without practical activities. The teachers of Grade 11 selected their learner participants based on their merits of relatively high marks in Paper 2 (chemistry) final examination and CASS tasks of Grade 10. The researcher chose these learners as sample because of limited time available for the intact classes to conduct research on the topic. For this reason, sufficient understanding of water related chemistry in Grade 10 was crucial for further understanding of the difficult aspects of topic in Grade 11. On the contrary, large and random learner samples would have been more costly in terms of time, resources and training for teachers, and this could underplay the efficacy of SI instruction. The research method of the study applied a quasi-experimental design that comprised small and purposive sample of learners appropriate for intact classes. The researcher designed and constructed practical-based inquiry activities that included LAM. Seven analytical instruments namely schedules of interviews and questionnaires, Research-based tests (RBT1 & 2), two class activities and a rubric assessment tool (RAT) for the learners' innovation research were used by the researcher to test learners' comprehension of concept, skills in the laboratory and application of these concepts and skills in the environment.

### **1.5 Structure of the dissertation**

Chapter 1 deals with exposition of the topic "Water Purification." The scholar introduces a detailed contextual background to the study from literature and justification of the

dissertation. The statement of the problem, the purpose of the study, the research questions and the concepts related to the topic were focused on chemistry of water purification, locally available materials (LAM) and Scientific Inquiry (SI) instruction.

Chapter 2 provides a review of the literature related to the teaching of the topic through SI using LAM and explains constructivism as the theoretical framework. Further to that the scholar compares routine practical work with inquiry-based practical work and explains the merits and demerits of SI. The implementation of SI in the old NCS and current CAPS documents are discussed at length. In this chapter the scholar discusses in detail the classification of types of inquiry in terms of learner autonomy and conceptualisation of LAM through improvisation in classroom instruction.

Chapter 3 focuses on the research design and research method. The research used a mixed mode approach within a quasi-experimental design. It also describes the population and sample and the instrumentation. The chapter elaborates the validity and reliability of the instruments, methods of data collection and ethical considerations.

Chapter 4 presents the analysis of the data, the results and discussion of the findings. Tables and graphs were used to highlight findings from statistical data. Descriptive statistics complimented statistical tools namely the analysis of variance, ANOVA and student statistic test, t-test, and validated the SI approach to teaching the topic “Water Purification.” Furthermore sample lesson plans, learners’ questionnaire, interview schedule and analysis, pre- and post-tests (RBT1 &2), practical activities and learners’ innovative research etc. are found in Appendices 1 to 14.

Chapter 5 closes the study with a summary, the limitations, conclusions and recommendations.



## **CHAPTER 2: LITERATURE REVIEW**

### **2.1 Introduction**

This chapter provides a review of literature relating to the teaching of chemistry at secondary school level using a Scientific Inquiry (SI) approach to the research topic “Water Purification”. The teaching strategy implemented in this study was built upon the following concepts, which are discussed here in detail: *conceptualisation of SI, curriculum implementation, aquatic and environmental chemistry of water purification, Locally Available Materials (LAM), difficulties in learning chemistry, and constructivist learning theory.*

### **2.2 Thoughts about Scientific Inquiry (SI)**

In their statistical analysis that included contrasts and combinations of results of various studies for 20 years regarding the efficacy of laboratory tasks, Hofstein and Lunetta (2003), observe that the term SI has been described in diverse ways and therefore still needs to be consistently and accurately clarified for the purpose of its application in school laboratories. In this study, SI had to be conceptualised since it was used for the purpose of assessment of learners’ performance in learning the topic “Water Purification.” The National Science Education Standards (NRC, 1996, p. 15) state, “scientific inquiry is at the heart of science and science learning.” The NRC believes that SI relates to the continuum of authentic class activities that help learners to master scientific knowledge and skills. The NRC (1996, p.23) defines scientific inquiry particularly as a complex multi-layered experience that comprises analysis; asking questions; analysing sources of data such as textbooks to obtain current knowledge, designing inquiries, evaluating previous knowledge based on empirical explanations, using instruments to collect, evaluate, and infer information; offer solutions, definitions, and hypotheses; and discussing outcomes. Inquiry in science requires distinguishing of hypotheses, use of analytical and consistent reasoning skills, and considerations of other descriptions related to phenomena under investigation.

Millar (1998) doubts the practicality of the school laboratory tasks to offer different but recognised thoughts on the definition and application of scientific perspectives. Millar (1998) describes these school laboratory experiments as some kind of practice in scientific inquiry that is pretentious in character and intended to influence results of laboratory investigations

so that they match with traditional answers. Nott and Smith (1995) illustrate the methods by which teachers control authentic classroom experiments so that they conform to the traditionally accepted practical procedure. Hanauer's (2006) research of primary school learners, describes how methods that use scientific inquiry, to facilitate different communication modes for instruction (e.g. verbal, text, visible and tangible or material structures) could lead learners to known explanations and results of the experiment(s). Numerous studies have investigated the guidebooks that were used in schools to guide SI activities in the laboratories. The first research of school guidebooks for practical tasks applied a taxonomy instrument called *The Laboratory Structure and Task Analysis Inventory* (Tamir & Lunetta, 1978; Lunetta & Tamir, 1979), which labelled three secondary school disciplines of natural sciences namely biology, physics, and chemistry. They discovered that

almost all investigations were highly structured and that seldom, if ever, are learners asked to: (a) formulate a question to be investigated; (b) formulate a hypothesis to be tested; (c) predict experimental results; work according to their own design; (d) formulate new questions based on the investigation (Tamir & Lunetta, 1981, p. 482).

They also point out that learners are “often asked to perform a variety of manipulative and observational procedures and to interpret the results of their investigations” (Tamir & Lunetta, 1981, p. 482). Germann, Haskins and Auls (1996, p.493) later investigated nine biology laboratory guidebooks applying the same taxonomy instrument and found once again similar results in the mostly teacher controlled biology laboratories. It appears that learners learning through inquiry in the science laboratory focus more on the experimental procedure that includes physical handling of apparatus than on mastering and realisation of scientific perceptions (concept).

### **2.2.1 Classification schemes of inquiry**

Flick (1995) notes that the main problems experienced by scholars regarding precise definitions of inquiry is that the term is universally used in education research, both as an approach to teaching and also as a procedure to do research. Due to the complex nature of SI pedagogy, the following questions are posed in order to determine the degree of independence of learners when they are engaging in classroom activities:

- To what extent does a teacher guide (direct) learner's activity in classroom?

- To what degree of autonomy (openness) is the learner given opportunity to construct own methods?
- How does a teacher assess learner performance?
- Is there a continuum of inquiries with varying degrees of openness?

In the literature, scholars dealing with secondary school pedagogy disagree on inquiry in terms of practice (Colburn 2000; Martin-Hansen 2002; Windschitl & Buttemer 2000). The definition of SI remains vague as Brown, Abell, Demir and Schmidt (2006) aptly write:

What makes this research difficult to understand is the lack of agreement about what constitutes an inquiry based approach. The bulk of the research has taken place in precollege classrooms examining the outcomes of various blends of inquiry based instruction. These studies are hard to compare given the differing meanings for inquiry that have been employed (p. 786).

The NRC (2000) describes inquiry as a range of classroom activities, and Brown et al (2006) extend this range with an illustration shifting from more structured (less autonomy) to less structured (more independence). These definitions provided framework for inquiry, but underplayed the precise definitions of the distinct levels of inquiry. Colburn (2000) notes that the term has dualistic usage in “teaching and doing sciences” (p. 42), and Anderson (2002) observes that the definition of inquiry by scholars lack clarity, and is too general and confusing. The NRC (2000) notes that because no universal, precise definitions of the levels and terms of inquiry exist, teachers and scholars have the freedom to define inquiry according to their procedures where appropriate (Anderson 2002). In order to address these discrepancies in definitions of inquiry Schwab (1962) and Herron (1971) submitted the first rubric that characterised inquiry in laboratory guidebooks. Herron (1971) determined the level of autonomy (openness) in the teaching by using teacher support as an instrument to characterise engagement of learners in inquiry laboratory. Herron’s Scale is an assessment instrument that utilises a simple question (i.e. “How much is *given* to student?”) as a framework to determine the degree of autonomy in learner’s engagement in an activity. This scale defines four levels of inquiry depending on the material the teacher or activity provides the learner; thus in terms of openness. The SI consists of three simple aspects that are pertinent to any scientific study: *a focus, a method, and an inference* (see Table 2).

Scientific inquiry is a complex model that is characterised by varying degrees and aspects that are difficult for many teachers and learners to understand, however the many levels of SI

can facilitate understandings as learners engage in deeper scientific arguments (critical thinking) during classroom activities. Learners should progress systematically from lowest levels to highest levels of inquiry through their learning stages over years. Teachers should attempt a combination of inquiry levels appropriate to the cognitive needs of their learners so that they [learners] can develop and practise inquiry skills that give them a holistic picture of science as a process and way of thinking.

### **Level 0: Verification**

The *focus*, *method*, and *inference* are given precisely or are known to the learners beforehand. The teacher gives learners the problem or focus of the investigation and guidelines that help them address the problem. The learners know beforehand the concepts that are being taught, and they know the solution to the problem in advance. This qualifies to be a more structured type of inquiry that verifies or validates a principle through classroom activity whose focus, method, and results are already known by the learners. In this study SI instruction was new to grade 11 participants, therefore this verification type of inquiry can help improve learners' further understanding of concepts and allow teachers to consolidate learners' prior knowledge on concepts. Teachers should be discouraged to give learners activities at verification levels only, as is the current practice in schools.

### **Level 1: Structured/direct inquiry**

The teacher gives precise *focus and method* to the learner, but learners have some degree of autonomy to draw their own inferences. Learners are often given opportunity to formulate a hypothesis about a phenomenon, and write down what they think will be the result of the practical investigation. In this type of inquiry, learners engage in an activity to investigate a problem given by the teacher using a structured method specified by the teacher. Here, learners now have some degree of autonomy because they can make their own inferences by analysing the data based on empirical evidence. Verification and structured inquiry activities should successfully be completed by learners particularly at primary school level in the senior and intermediate phases because they are basic and therefore crucial for further understanding of more complex guided and open inquiries at secondary school level.

## **Level 2: Guided inquiry**

The teacher provides *research focus or problem* to learners who now have more autonomy to design their own procedure and arrive at their own conclusions and recommendations. This type of inquiry gives learners opportunity to address the research problem through argumentation or critical thinking skills that explain their findings or results backed by empirical evidence. Guided inquiry is less structured and has higher degree of openness that gives learners opportunities when choosing procedures, materials, data collection and execution, and inferences. Here learners take more responsibility of their learning process because they are more actively involved during the activity under investigation. Because this type of inquiry is more learner centred than the structured inquiry, it becomes most useful when learners are provided many opportunities to practise research design, methodology, collection and analysis of data. In this study the teacher presents the topic Water Purification to learners to analyse and construct knowledge in a collaborative learning environment. The topic that poses an authentic scientific problem and an active collaborative learning environment seem to be the critical prerequisites that should be created by the teacher using this type of SI instruction in classroom. The teacher's role should not be docile because learners have greater autonomy here; instead, he or she should continue to give them guidance in a systematic way so that learners' investigations progress well.

## **Level 3: Open inquiry**

This is the highest level of inquiry whereby learners take full autonomy of all skills of investigation that comprise *focus, method and inferences*. Learners' activities in this type of inquiry involve identifying their own research focus, developing methods that address their research focus, collecting and analysing data, and using systematic thinking skills backed by empirical evidence to reach and support their own outcomes. This level is less structured and demands highest cognitive levels and maximum scientific logic. In open and authentic inquiry-based learning, learners work like their counterpart scientists in professional laboratories, and apply the rigorous SI process that may incorporate active learning approaches such as Process-Oriented Instruction (POI), Prediction, Observation and Explanation (POE) and Modelling. In an authentic SI instruction such as the case in this study, an applied hypothetical type of inquiry was methodologically used to apply chemistry

learnt in the classroom to solve a particular real-life problem (i.e. water purification) through classroom activities.

- **Prediction, Observation and Explanation (POE):** This is an empirical method of inquiry with a practical aspect in which learners envisage outcome of a phenomenon and suggest logical inferences thereof before experiment (Chiu, Chou & Liu, 2002). This type of instruction is ideal for smaller classes, because fewer learners will have opportunity to discuss their scientific arguments in class before an experiment is done, and scenario is not so in large classes.
- **Modelling:** Gilbert (in Gobert 2000:891-894)) and Buckley (2000) observe that simplified demonstration of ideas, in complex events or objects makes clear their aspect, and on the contrary this practice may complicate these aspects if not correctly utilised. In order to achieve the projected target and to minimise advent of rival conceptual frameworks; modelling boundaries of observation should be well defined. Therefore a thorough examination of phenomena has to be done before modelling is employed such as the case in Figure 4: model diagram of water purification (recycling) at household level.

Grade 11 learners; if given sufficient time and practice at first three levels of SI, they will be able to carry out open-ended inquiry activities with minimum guidance from the teacher. Learners should first be able demonstrate that they are able to plan and conduct an investigation when given the problem, in doing so they would have successfully completed Levels 0 and 1 (more structured levels with less degree of autonomy). The topic chemistry of water purification gives learners opportunities to experience numerous levels of inquiry during a single engagement in classroom activities. This is so; because the topic is abound with linked chemistry concepts that manifest at each of the five stages of water purification. Learners need a lot of practice that engages them in classroom activities to enhance their inquiry skills and understandings to an extent where they accomplish total independence, and are able to engage in authentic inquiry activities, just like what scientist do. Table 2 showing the four levels of inquiry obtained from combinations of inquiry skills and degree of learner independence that was provided to the learners by the teacher or classroom activity.

**Table 2: Classification schema of learner independence in the pedagogy of inquiry<sup>2</sup>**

Type of inquiry	Focus	Methods	Inferences
Level 0 (Verification)	Known	Known	Known
Level 1 (Structured/Directed)	Known	Known	Independent
Level 2 (Guided)	Known	Independent	Independent
Level 3 (Open)	Independent	Independent	Independent

They [Herron & Schwab] coded each aspect of inquiry (*focus, methods and inferences*) as *given* (known), (less autonomy: teacher support was offered), or *open*, (independent), (greater autonomy: teacher support was absent).

Chinn and Malhotra (2002) designed and constructed an alternative research methodology that characterised scientific inquiry through the technique of analysing school textbooks for practical activities, which they used to compare the knowledge and aspects of proficient science with SI in the school laboratory. They found three distinct types of directed inquiry tasks: experiments comprising only one factor of experimental plan, observations that involve careful thought and explanation of a phenomenon, and distinct and clear examples of science objectives, which are guided by an explicit method. The scholars [Chinn & Malhotra] compared forms of school SI to professional SI in terms of the reasoning practices that was required and the conceptual thoughts (nature) of the work, and found the following:

As for conception of questions and study design, SI in schools is teacher-centred and linear in sequence with learners following instructions, whereas scientists work more freely as far as problem solving is concerned. Regarding observations, explaining results, and generating theories about a phenomenon, scientific inquiry in schools is way of thinking and understanding and directly solve research problems that exclude the complications of

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<sup>2</sup> Source: (Schwab 1962 & Herron 1971)

participant partiality, information alteration, methodological errors, general application of findings, theory conception, contradictory data and discrepancies, and studies that are more comprehensive. In professional science, the challenges and existence of any scientific declaration raises an obvious worry. In fact, proficient scientific inquiry involves the creation of knowledge through diverse forms of inferences of a scientific thought within the broader community of scholars. On the other hand, SI in schools is irrelevant to the broader fraternity of scholars because it [SI] reproduces understanding of phenomena. SI is also restricted as far as inferences or argumentations are concerned. According to Chinn and Malhotra (2002), scientific inquiry in schools is expected to yield findings for individual purposes and not for the wider community of practices. In order to define the thought of scientific inquiry within which a variety of tasks are carried out, Wenning (2005; 2007) developed the following different forms of scientific inquiry that distinguishes procedures and didactic practices of inquiry-based tasks from extent of teacher control, which in turn requires lot of proficient complexity.:

**1. Discovery Learning:** The teacher uses the very conventional approach to direct task and to instruct learners to note particular aspects of phenomenon and repeat established inferences.

**2. Interactive Demonstrations:** Learners are novices who learn under the expertise of the teacher who controls and manipulates methodology of experiment, hypothesis, or a description of the phenomena. The tutor is in full charge of the scientific processes that include the experiment, formulation of hypotheses or questions and clarifications of phenomena based on evidence or findings.

**3. Inquiry Lessons:** The procedure of an experiment is directed and manipulated by the teacher through verbal explanations of theoretical and practical aspects of the practical model. The teacher also asks important questions and replicates the intellectual processes involved in scientific inquiry.

**4. Guided Inquiry Labs:** Learners conduct a scientific inquiry that is guided by a question posed by the teacher and laboratory procedures are defined and guided by the instructor.. According to Herron (1971), the teacher assists learners to find the solution to a particular problem using prescribed conventional approaches to inquiry. This form of inquiry



dominated the bulk of instruction in this study, particularly in practical activities that used LAM to clarify water.

**5. Bounded Inquiry Labs:** The tutor identifies and asks a question. The learners are expected to plan the experiment and carry out the scientific inquiry (Herron, 1971). This approach was implemented in the group's research design and construction of water purification devices for use at household level.

**6. Free Inquiry Labs:** The learner identifies and asks a question and also plans and carries out an inquiry process.

**7. Pure Hypothetical Inquiry:** Learners develop clear understanding of theoretical laws and of natural phenomena based on experiential evidence.

**8. Applied Hypothetical Inquiry:** A particular realistic life problem is solved by the learner through a problem solving learning approach that uses hypothesis generation based on actual scientific knowledge wherein results are supported through reasoning. In this study, water purification was envisaged as an authentic problem that is integrative and context-based.

Wenning's (2005, 2007) theoretical organisation of different forms of scientific inquiry, founded on Herron's (1971) previous effort, elucidates the difficulty related to definition of the term "scientific inquiry" that is currently too generic and covers a diversity of science activities that include learners' scientific knowledge within the world of scientists. Grade 11 learners who studied within this SI framework were given the autonomy to contextualise scientific inquiry practices that link theory, laboratory experiences, and application in the environment of the chemistry of water purification. Therefore, they [learners] were not supposed to master the complex nature of scientific inquiry. Within these SI practices, learners were expected to present their scientific knowledge in authentic scientific communications such as presentations and project write-ups. For the purpose of developing an assessment apparatus, Hanauer (2007) examines the inquiry process of science in a specific school laboratory-based curriculum from a perspective that involve processing of data from a wide variety of modes of communication such as visual, textual, aural etc. (Hanauer, 2006). According to Hanauer (2007), the examination of inquiry process in science in a school laboratory integrates four varieties of knowledge that are:

1. **Empirical knowledge** comprises hands-on skills (empirical skills) and experiences needed to conduct the laboratory tasks of scientific inquiry.
2. **Symbolic knowledge** comprises different modes of communication for processing information in scientific formats such as the text and visible representations (visualisations) that include formulae used within the laboratory.
3. **Critical thinking knowledge** comprises contextual science matter (content) and intellectual or cognitive capacity that include the use of logic in solving problems, making decisions, and computations.
4. **Reporting/writing knowledge** comprises the descriptive skill to review and understand research and organise (science heuristic writing skills) them in the formats that benefit wider community of scholars.

In the light of the consideration of the four forms of knowledge, the term scientific inquiry is thus defined here as a process that allows assessment tools to be generated at each stage of a scientific inquiry process.

### **2.2.2 Ideas of the National Research Council (NRC) on Scientific Inquiry (SI)**

According to Barrow (2006) and Duschl and Grandy (2008) the term Scientific Inquiry (SI) has been crucial in science education studies for several years. Some examples of researchers' efforts to understand SI are that many teachers have designed inquiry-based science programmes and resources (Linn, Clark, & Slotta, 2003) and accompanied them with comprehensive manual programmes (Schneider, Krajcik, & Blumenfeld, 2005), that have been involved in expert skills development projects (Songer, Lee, & McDonald, 2003), and constant physical observation and assistance of scientific inquiry in progress during classroom instruction (Fishman & Krajcik, 2003). Some scholars have studied diverse approaches to teaching and learning through science inquiry (Bransford, Brown, & Cocking, 2000), and these include scientist placements (Barab & Hay, 2001). Anderson (2002) and Barrow (2006) observe that despite these widespread resolves to apply inquiry in classrooms teachers still face difficulties concerning the progress of science education. For instance, science lessons in the USA classrooms usually ignore inquiry (Weiss, Pasley, Smith,

Banilower, & Heck, 2003), as several teachers practise an instructional approach that simply allows learners to recite science concepts/topics from their textbooks (Stake & Easley, 1978).

In an effort to bolster SI instruction in schools and quell traditional teaching practices, a variety of principles in the form of guidelines has been developed. Of particular note is that the *Benchmarks for Scientific Literacy* expounded by the American Association for the Advancement of Science (AAAS), (1993) and *National Science Education Standards (NSES)* of the National Research Council (1996) are the most popular guidelines that are being cited so far. According to Anderson (2002), the purpose of such efforts is that guidelines provide teachers with holistic and hands-on strategies that assist them to successfully apply inquiry in the present school systems. The standards also strive to arrive at a definite and collective understanding on the objectives of inquiry in education that function as a clear guide for scholars given the current vague definition of SI, which is too ambiguous for collaborative action (Barrow, 2006; Cuevas, Lee, Hart, & Deaktor, 2005). The three forms of inquiry stated by the NSES (NRC, 2000) are as follows:

- Inquiry as teaching strategy: engaging learners in scientific inquiry through hands-on experiments
- Inquiry as content: developing scientific inquiry skills, and
- Inquiry as content: understanding the nature of science or scientific inquiry.

The teaching of sciences through SI approach is embedded in the constructivist learning theory and environments. In this research, the SI as an instructional approach encourages learners to construct scientific meanings in a dynamic and collaborative environment and to work with materials readily available from their local environment. The material standards of the NRC, which holistically define SI, constitute three aspects of science that are conceptual science (knowledge content), skills of scientific inquiry, and science as a body of knowledge and a philosophy (nature of science).

**Scientific inquiry skills:** in order to teach science as a form of a philosophy (Schwab, 1960), the following practical inquiry skills are often classified and teachers should attempt to advance those skills in learners: “identifying scientific questions; designing and conducting a scientific investigation; analysing and interpreting data; developing explanations based on the evidence; communicating and justifying the explanations” (NRC, 2000, p. 29). Many of these skills which constitute aspects of SI that are related to laboratory-based activities will be

utilised in the implementation of the teaching strategy for this study. Zee, Hammer, Bell, Roy and Peter (2005) argue that even if the empirical explanations of inquiry fail to provide a holistic definition [picture] of scientific inquiry, the explanations assist learners to participate in scientific reasoning that produce systematic thinking processes. Windschitl (2004) also notes that all aspects of inquiry are interlinked and that there is no single scientific technique that dictates how scientific tasks should be conducted, because questions, procedure and answers are always different from one particular situation to another.

**Nature of SI:** According to Abd-El-Khalick (2004) and Lederman (2004) the current understandings of science as a body of knowledge and a philosophy includes science as (a) a resolve to explain natural events; (b) knowledge that is faltering; (c) dynamic and practical-based knowledge (d) highly conceptual and abstract by observation; (e) innovative and explanatory through scientific perspectives; and (f) being part of socio-ethical practices.

According to the NSES (NRC, 2000) the following is a short of what it values in teaching science through inquiry for scientific literacy:

- (a) Because learners build new knowledge on what they already know, teachers need to utilise learners' prior understandings in their teaching.
- (b) Because understanding science is more than knowing facts, learners need to experience authentic scientific inquiry.
- (c) In order to encourage effective learning, teachers need to guide learners to generate appropriate questions that are scientific and relevant (NRC, 2000, p. 24-33, and 116-20).

The NSES (NRC, 2000) claims that “how” questions are of higher cognitive order than “why” questions for science teaching and learning since why questions are based on knowledge and empirical skills, whilst how questions, which seek reasons to an action that produces a result, are often used in scientific inquiry. As learners construct knowledge and acquire practical skills through experiment and observation in the laboratory they would be using the why questions to provide answers to their hypothesis. The why questions provide answers which explain the observed experimental results particularly the hypothesis. Science is dynamic and practical-based knowledge that constitute actions (variables) and results that can be addressed by how questions which provide answers to describe events through analysis of experiment or observation of effect. The how questions and why questions are so

organically interlinked that an attempt to artificially break them down, would make understanding of concept difficult for learners, more so in SI activities.

### **2.2.3 Comparison of traditional and inquiry-based laboratory chemistry**

Lunetta, Hofstein and Clough (2007) claim that the laboratory has assumed its crucial role in science education, particularly in chemistry because of some unique practices associated with learning science in a laboratory. Learning chemistry in a laboratory offers learners opportunity to use their hands to feed their minds and develops in learners critical intellectual skills of reasoning that enable them to answer “how” and “why” questions by combining their knowledge and observational skills to explain phenomena. In recent years, many scholars have suggested that the efficacy of science laboratories as powerful learning organisations makes learning productive (e.g. Abrahams & Millar, 2008; Lunetta et al. 2007). In this study, SI (laboratory) activities are defined as learning experiences through practical activities in which learners interact with locally available materials (LAM) to learn the chemistry of water purification. In the practice of school laboratory four main types of experiments can be identified as investigative, inquiry, discovery and confirmatory. The SI approach to teaching used in this study focused mainly on investigative or inquiry-based experiments. Fradd, Lee, Sutman et al. (2001) for example categorised experiments depending on whether they were open-ended or not. The experiment is described “open” when it is conducted solely by the learner and “closed” when it is carried out solely by the teacher. A confirmatory investigation is “closed” because the learners, following understanding concept in science lessons, perform a methodological process that is directed by the instructor as prescribed in the textbook. This linear approach is rhetorical, replicates traditional results, and is deductive in nature since both parties may know results beforehand. On the other hand, an inquiry trial is classified as “open” for example in free inquiry laboratory practice, when the learner identifies and asks a question, formulates a hypothesis and plans and conducts an experiment. This non-linear approach is student-centred and inductive, because both parties may be unacquainted with results of the experiment. According to Cazden (2001) in a conventional science lesson teachers hastily give formative feedback to learners when they respond to questions with expected answers. In contrast, in a SI approach, learners working in small groups solve authentic scientific problems, which in turn, create an active learning environment for them, particularly if the problem is context-based like chemistry of water purification.

A number of scholars for example (Gott & Duggan, 2007; Sampson & Gleim, 2009) claim that the practice of inquiry in a school laboratory has the prospect to advance learners' critical thinking abilities. For instance, Tien and Stacy (1996) report that learners in middle schools in Korea who took part in teacher directed investigative-type of learning in the laboratories acquired more experience at analysing their performance in school tasks than those who did not participate. Kim and Song (2006) evaluate the logical reasoning of learners by posing flexible and investigative-type of questions in the process of learning and afterwards. These scholars propose supplementary guidelines that help learners to defend their experiences of events and to function as critics in the same way as scientists do at presentations. The guidelines infer to the practical tasks that include procedure and observation, the representational knowledge in scientific formats such as written reports, presentations etc. and constant feedback accompanied by teacher's comments to enable learners to progress with their work. Watson, Swain and McRobbie (2004) claim that students in environments with low levels of critical thinking regarded the laboratory as exit to methods that would facilitate outcome of a practical investigation such as a report writing, but they did not think of the laboratory as an environment for debate and methodical reasoning.

Some scholars (Hohenshell & Hand, 2006; Keys, Hand, Prain et al. 1999) claim that the output of a written report in the form of Science Writing Heuristic (SWH) is the best skill that learners can demonstrate in the laboratory, and this practice should supersede the routine approach, which is used by many learners to organise reports mostly after confirmatory laboratory experiments. Teachers should give students written directions so that they conceptualise and link key aspects of SI process such as observation, hypothesis (questions), collection of evidence and explanation of findings. Teachers should ask learners "how" and "why" investigative or inquiry-type questions that link aspects of SI process and, in turn enable learners to construct knowledge that justify their explanation of phenomena based on evidence or data collected. Yoon, Bennett, Mendez et al. (2010) describe an ideal classroom environment that uses SWH approach to enhance learning as one that respects students' views, accommodates reproach, cares for others, and appreciates role modelling of teachers.

Hofstein and Lunetta (2004) observe that laboratory practices enhance learner's understanding of science concept when they are combined with other empirical knowledge skills such as "predict-explain-observe" experiments, etc., and this includes the use not only of materials and procedures, but also of ideas. The results of the study by Hofstein, Navon, Kipnis and

Mamlok-Naaman (2005) show that experiences in the laboratory enhance students' capacity to probe more productive questions that link experimental observations and results. The laboratory provides a real learning setting for scientific inquiry tasks, and improves learners' mastering of concept (Lord & Orkwiszewski, 2006), process skills of science (Deters, 2005; Hofstein, Shore & Kipnis, 2004), perceptions towards science (Gibson & Chase, 2002; Jones, Gott & Jarman, 2000; Lord & Orkwiszewski, 2006), interest in learning science (Tuan et al., 2005), comprehending the world of science (Backus, 2005), and communication skills (Deters, 2005).

#### **2.2.4 Merits and Demerits of Scientific Inquiry (SI)**

The present study offers a more practical approach to pedagogy in teaching chemistry, wherein learners are allowed to construct knowledge in a collaborative environment. SI instruction that manipulates LAM provides opportunities for learners to construct new understandings of phenomena, and in turn apply these new learning experiences to solve context-based problems or scientific-socio-ethical issues in their local environment. Learners engaged in SI activities are intrinsically motivated to learn as they play an active role in argumentation about a problem. SI instruction promotes learners' problem-solving skills rather than replicating traditional topics in science. Learners do not learn science for recall in examinations only, but they learn it in such a manner that it has a long term bearing on their lives. The SI instruction used in this study provided learners with a collaborative approach to problem solving by creating a constructivist learning environment in which learners solve problems through a variety of approaches that are facilitated by group interactions. Team members are responsible for each other's actions as they take ownership of the problem, such that failure to solve the problem is not just an individual's failure.

Some teachers claim that SI instruction is a protracted approach that prevents teachers from covering all topics in the work schedule for a specified term because just three periods of 45 minutes each are allocated per week in a typical high school timetable in South Africa. Recent studies suggest either that SI practice in most schools worldwide is completely absent or if present it is minimal, and this includes those schools that use advanced curriculum for science. The practicality of SI in schools is rather rhetorical, because most schools still follow didactic methods of teaching, worse still in developing countries where there are challenges

of practical infrastructures in schools exacerbated by teachers' lack of knowledge about SI and limited curricular methodologies to implement SI instruction in schools.

### **2.3 Curriculum implementation**

This study takes into account the educational value of chemistry of water purification concerning implementation of chemistry curriculum and pedagogy for Grade 11 learners in Limpopo Province of South Africa. The study also considers the topic ideal for Grade 11 learners, because it is context-based and stimulates learner's interest since it is close to the learner's everyday life experiences. According to Malcolm (1999), the move to Curriculum 2005, (C2005) has not been complemented with a change in teaching and learning materials such as textbooks. The C2005, the South African brand of outcomes-based education (OBE) was the teaching and learning blueprint for schools that was supposed to be fully implemented by 2005. The C2005, OBE as an approach to facilitate learning and was expected to develop in learners logical reasoning. Water purification is not prescribed as specific subject matter (content) in the NCS or the new CAPS, but basic aquatic chemistry and environmental chemistry topics such as the water cycle are specified in Grade 10. The research topic can be assessed as one of the formal tasks for external assessment or Continuous Assessment (CASS), or as an informal task for internal assessment or school based assessment. According to Umalusi (2006, p. 18), the use of a combination of external and internal assessment continues to gain extensive recognition from stakeholders in the education fraternity. A shift in practice that also considers internal assessment has an advantage of assessing learners on diverse skills over lengthy time and provides a more reliable performance of learners that complements the final examination. In addition, internal assessment allows teachers to focus specifically and timeously on learning problems of learners because learners need prompt feedback on their individual's progress.

By Grade 10, learners should understand basic aquatic chemistry of phase changes (investigation of the heating and cooling curves of water), the molecular structure of water, the physico-chemical properties of water such as solubility and conductivity, and environmental issues of the water cycle such as the pollution of water sources (see section 2.4). The Physical Sciences curriculum stipulates, by means of Learning Outcomes (LOs), that the teaching of subject matter should be accompanied by acquisition of skills, knowledge and values by the end of the Further Education and Training (FET) band. The three Learning



Outcomes, which are specific for Grades 10 to 12 Physical Sciences, are stated below (Department of Education, 2003, p.p.13–14):

- LO1: scientific inquiry and problem solving
- LO2: constructing and applying scientific knowledge:
- LO3: the nature of science and its relationship to teaching, society, and the environment

The three LOs are expected to produce learners who are equipped with concrete mastery of chemistry, reasoning skills, interactive and collaborative skills that guide them as they use LAM to carry out their practical activities in the classroom. The old NCS and new CAPS documents require that physical sciences learning should be approached from a multidimensional viewpoint using SI that integrates real world experiences of learners by linking theory, practice in the laboratory and application in everyday life.

In the National Curriculum Statement (NCS) all Physical Sciences learners in Grades 10–12 are required to undertake one research project task per year as part of their Continuous Assessment (CASS) to master concepts, and in turn, that will complement the final examination. In 2012, a new curriculum, the CAPS (DoE, 2010), was implemented for the first time, starting with Grade 10. In CAPS, one proposed chemistry or physics project, or an integrated chemistry or physics project, is prescribed for Grades 10–11 per year as part of formal assessment. The DoE recommends that the project should be started early in the first quarter so that learners can have adequate time to plan the project by writing a project proposal that includes design. The final assessment of the project is done and recorded in the third term. In Grade 12, no projects are required. According to DoE's CAPS (2010, p.p. 6–11), learners' projects and laboratory practical investigations in Physical Sciences should be guided by hands-on skills (physical knowledge) that specifically include procedural skills needed to solve investigative-type tasks and problem-based tasks. The only differences between the old NCS and the new CAPS requirements is that in the former, projects are completed in one term and Grade 12 learners also complete a research project for CASS. Under the new CAPS and NCS assessment, learners are tested on their effective application of investigative skills in science through planned activities that are presented in experiments and projects. These anticipated inquiry skills are “planning, observing and gathering information, comprehending, synthesising, generalising, hypothesising and communicating

results and conclusions”. According to DoE’s CAPS (2010) an experiment is performed to confirm or analyse an established concept, whereas a practical investigation is an experiment that is performed to try a hypothesis or question. According to DoE’s CAPS (2010, p.p. 6-11) projects comprise the following examples:

- (i) designing and creating a poster on suggested topics
- (ii) designing and construction of a prototype device, for example electric motor, water purification device
- (iii) designing and building a physical model of a concept in the FET Physical Sciences curriculum
- (iv) carrying out a prescribed practical investigation.

The instruments that are used for assessment of learners’ practical tasks include, but not limited to the following devices: marking guidelines, worksheets, experiment-result list and grading/scoring outlines (see Appendices 3, 7, 8 and 9). The definition of practical tasks is rather vague here, because research projects are not specified, and more often than not teachers and learners confuse practical investigations with research project, worse still when the prescribed experiments are regarded as research projects when indeed they are simple experiments as is routinely the case. Regardless of this confusion, the new CAPS approves a long period of time for conducting learners' research, thus reflecting the significance of this approach to SI instruction in schools.

The Department of Water Affairs and Forestry (DWAF) (2010) in partnership with the DoE runs the Water Education Programme (WEP), in schools that has so far facilitated capacity building of teachers to enable them guide learners’ projects related to application of sciences to water related issues such as water conservation. According to the DWAF’s (2010, p.p. 1-5) WEP in schools, from 1997 to date more than 10 000 teachers (teaching Grades 5 to 9) from 10 000 schools have been trained in facilitating learners' research in water-related issues such as water science audits, innovations of water purification, sanitation, etc.

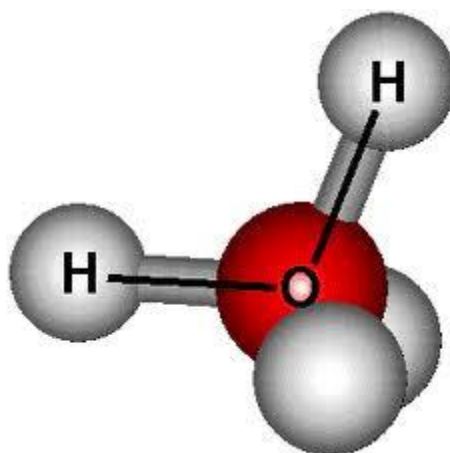
Learners are urged by WEP to perform the following water-related projects and activities:

- qualitative laboratory analysis of municipal water using DWAF test kits to detect and identify contaminants, and to inform the local authority accordingly
- water audits (quantitative studies) of municipal water that include supply and consumption for the purpose of conserving this natural resource in sustainable ways
- protection of local wetlands and monitoring of their biodiversity
- competitions such as the South African Youth Water Prize (SAYWP), which has benefits such as motivating learners to use innovative approaches to solve water-related problems through research projects that apply science and technology.

This study seeks to complement DWAF's work to promote water related projects in schools and the DoE's recommended practical tasks by teaching aquatic chemistry and chemistry of water purification using LAM that enable learners to master the difficult concepts of the topic

## 2.4 Aquatic chemistry and chemistry of water purification

See lesson plans 1, 2 and 3 (Appendices 5, 7 and 8).



**Figure 1: Model of Water Molecule<sup>3</sup>**

Water is life and it is said to be a universal solvent; a basic stuff of the universe. Water has a simple molecular structure composed of one oxygen and two hydrogen atoms. A shared pair of electrons (bonding pair) in oxygen atom covalently binds to each hydrogen atom. Oxygen atom has a valence of six, and is short of two electrons to complete octet rule (stable electron

<sup>3</sup> Source: [Online]. Available at [Isbu.ac.uk, 2011]. This three dimensional structure of water is very difficult for many learners to visualise, and in turn these learners hold misconceptions about science of water.

configuration). In water, there are four pairs of electrons surrounding the oxygen atom, two pairs make up covalent bonds with hydrogen, and two lone pairs (unshared pairs) on the other side of the oxygen atom.

The lone pair of electrons on oxygen atom makes it more more electronegative atom than the hydrogen atom, owing to small net negative charge ( $\delta^-$ ) by the more electronegative oxygen atom and small net positive charges ( $\delta^+$ ) by the less electronegative hydrogen atoms that cause unequal spread of electron density. For this reason, water ( $\text{H}_2\text{O}$ ) is a covalent polar molecule, and has a bent or angular structure (see Figure 1). It exists as liquid at standard pressure and temperature as a result of its unique hydrogen bonding. Water exists in three phases: ice/solid, liquid and gas/water vapour.

### **Water as solvent**

Polarity also renders water its solubility properties that are very important in solution chemistry, for example biochemical reactions and chemical change in chemistry occur in aqueous solutions. Water soluble substances are ionic and polar owing to their dipole poles; examples are salts, alcohols acids and gases such as hydrogen chloride and hydrogen sulphide. Non-polar substances such as fats and oils are water insoluble, because it is more energetically favourable for hydrogen bonds to stay together than to bond the weak intermolecular forces of Van der Waals forces with these non-polar molecules which have no dipole moments.

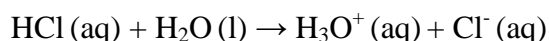
### **Conductivity**

“Pure” water is uncommon in nature because of water’s solubility properties. Water is always self-ionising depending on factors such as temperature, and this makes it a weak electrolyte, but “hard” water, mainly from ground water that contains mostly metal ions of  $\text{Mg}^{2+}(\text{aq})$  and  $\text{Ca}^{2+}(\text{aq})$ , is a strong electrolyte.

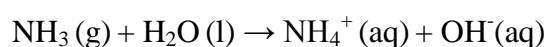
### **Reactivity**

Water is amphoteric and can act as an acid or a base. At a pH of 7 (neutral), which is rare, the concentration of hydroxide ions ( $\text{OH}^-$ ) is equal to that of the hydronium ( $\text{H}_3\text{O}^+$ ) ions. If the equilibrium is disturbed, the solution becomes either acidic owing to a higher concentration of hydronium ions, or basic, the result of a higher concentration of hydroxide ions. According

to the Brønsted-Lowry system, an acid is a proton donor (an  $\text{H}^+$  ion) in a reaction, and a base is a proton acceptor. When reacting with a stronger acid, water acts as a base; when reacting with a weaker acid, it acts as an acid. For instance, it receives an  $\text{H}^+$  ion from  $\text{HCl}$  in the equilibrium:



Here water is acting as a base, by receiving an  $\text{H}^+$  ion. An acid donates an  $\text{H}^+$  ion, and water can also do this, such as in the reaction with ammonia,  $\text{NH}_3$ :



### **pH of water**

In a state of equilibrium, the dissociation constant of water as well as the ionisation of hydrogen ions from water increase with an increase in temperature. Water dissolves acidic gases such as carbon dioxide and sulphur dioxide to form weak acids called carbonic acid and sulphurous acid respectively, this is particularly so in formation of acid rain. The pH of deionised water at room temperature is approximately 7.0 because water is always self-ionising.

The pH scale ranges approximately from zero to 14: acids range from 0 to less than 7; neutral equal to 7 and; bases range from greater than 7 to 14.

pH is defined as the negative logarithm to base 10 of hydrogen ions concentration in a solution.  $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+(\text{aq})]$  where  $[\text{H}_3\text{O}^+(\text{aq})]$  is concentration in  $\text{M}$  or  $\text{mol dm}^{-3}$  of  $[\text{H}^+(\text{aq})]$  ions in aqueous solution, so in deionised water at room temperature  $[\text{H}^+(\text{aq})] = 1,0 \times 10^{-7} \text{ mol dm}^{-3}$  hence  $\text{pH} = -\log_{10} (1,0 \times 10^{-7}) = 7.0$ .

### **Clarification of water**

In natural aquatic ecosystems for example wetlands, streams and estuaries such as streams, plants improve quality of water because they function as buffers that filter and process sediment (deposits of soil) and debris, plant and animal waste, and metal and non-metal ions, and microbes before they are emptied into rivers.

Wastewater (grey water) and natural water contains inorganic impurities such as mineral salts, mineral acids, trace elements, fine metals, metal compounds and organometallic compounds. Toxic heavy metals such as copper or zinc that are soluble, including insoluble mercury, lead, cadmium and nickel which bio accumulate in aquatic trophic chains and may be present in grey water. Grey water from septic tanks may also contain sediments such as sand, silt, clay and gravels including physical (solid) impurities that are separated from water by filtration and sedimentation processes. Grey water purification is a process uses different techniques to clear water of solids, bacteria, algae, plants, inorganic compounds and organic compounds from water. Water is purified for the purpose of making it suitable for use in the environment, even pleasant for human drinking.

The variety of technical expertise that could be utilised during the process of water clarification at a civic facility differ on types of water impurities the set specifications and existing capital for investment.<sup>4</sup> For the purpose of teaching the research topic water purification effectively to Grade 11 learners, five common stages of clarifying water at household level, using LAM as demonstrated in the SI instruction discussed in Chapter 3 with particular reference to the chemistry occurring at each stage. (see section 3.8.2 & Appendix 7).

#### **2.4.1 Stage 1:Pre-chlorination**

Grey water from septic tanks is pre-chlorinated by adding bleach that deactivates and kills many pathogens after it has been treated in aerobic units to separate solids such as sand, silt, gravel and scum, which block the sand-filter bed.

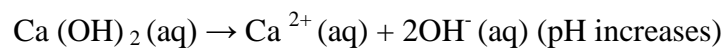
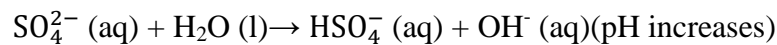
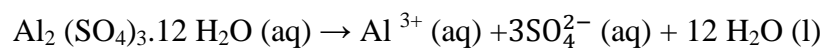
Pre-treatment of grey water comprise five stage processes of coagulation, flocculation and sedimentation. Colloids (mainly deposits of soil) are suspended, solid particles, for example clay particles in water that carry same negative surface charges, and repulsion prevents them from aggregating (collecting). Colloids through process of coagulation are neutralised by combining chemically with ions in water forming masses of particles called flocs or aggregates (alum and sediment plods) that settle to the bottom (i.e. sedimentation). Coagulation is achieved by the addition of electrolytes such as aluminium sulphate and lime

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<sup>4</sup> There are many available large scale, sophisticated and high technology methods for purifying water. The process chosen for this study is simple for learners to understand because it applies basic chemistry that is relevant in their daily lives Part of this section is adapted from [Online] Available at [<http://building.en.wikimiki.net/en/public+works>].

in water. Flocs trap solid waste particles in water. In a process of sedimentation using silt gravity pulls the particles of aggregates to the bottom of the container. During this step, the water becomes colourless, ready for filtration. Coagulation and flocculation removes impurities such as suspended iron (III) oxide particulates and organic matter, which give water its muddy yellow aspect.

Grey water water is cleaned by treating it with electrolytes such as alum  $\text{Al}_2(\text{SO}_4)_3 \cdot 12 \text{H}_2\text{O}$ , and lime,  $\text{Ca}(\text{OH})_2$ , which increase the pH of the water and becomes more basic as a result of the following reactions:



$\text{Al}(\text{OH})_3(\text{s})$ ,  $\text{Fe}(\text{OH})_3(\text{s})$ , and  $\text{Fe}(\text{OH})_2(\text{s})$  precipitate in alum, bringing the small particulates with it and the water becomes clear. Some salts such as iron sulphates  $\text{Fe}_2(\text{SO}_4)_3$  and  $\text{FeSO}_4$ , and chromium sulphate  $\text{Cr}_2(\text{SO}_4)_3$  can also be used as electrolytes during coagulation. Ions of sodium, chloride, calcium, magnesium and potassium also affect the coagulation process, as do temperature, pH, and concentration.

#### **2.4.2 Stage 2: Sand-filter chamber**

In filtration process sand filters remove the remaining solid particles and floc from the water through biological, physical and chemical processes.

Organic matter breaks and particles stick to sand surfaces or are trapped in sand spaces during seeping of water in recurrent doses through the sand filter beds. Negatively charged sand surface grains attract positively charged waste materials and bond by adsorption. Some waste particles bond chemically with the sand filter media, and are also removed.

After sand filtration process, water collects in the underground drains, some is directed back to the recirculation tank where it mixes with septic tank effluent and is recirculated to the sand-filter chamber for further treatment before passing through carbon and chlorination chambers (see Appendix 4).

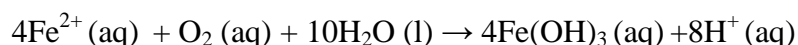
After about two weeks, the sand filter develops a filter ecosystem, a thick surface layer called biomat, rich in bacteria, which feeds on the trapped organic waste particles. Within this trophic level, protozoa in turn feed on bacteria and prevent the biomat from blocking the sand filter. This food chain in the filter ecosystem, together with physical and chemical processes, makes water colourless and odourless. As for regular maintenance, the top layer of the sand filter must be removed as the biomat becomes blocked. The water collects in the underground drain and flows into the carbon-filter chamber, which removes chemical impurities. Grey water treated by sand-filter beds is usually colourless and odourless.

Soil particulate texture affects rate of filtration. Sand or sand silt particles have a relatively larger diameter than fine sand particles. Rapid sand filters with an effective size range of 0.45mm, made up mostly of sand silt, are the most common media for the physical treatment of water. Slow sand filters with an effective size range of 0.25-.035 are fine sand media used in spacious land to treat water at the surface more biologically than physically. They are carefully constructed using ordered layers of sand with the coarsest at the base and the finest at the top, such as in the model diagram in Appendix 4.

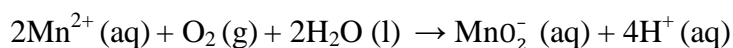
Materials suitable for filter media must be of constant composition, uniformity and depth. LAM such as sand, silt gravel of different textures, crushed glass, mineral particles and bottom ash can be used for domestic water application. Characteristics of a good filter medium that should be considered in filter design is that it should be insoluble in water, have neutral pH, be hard and be washed thoroughly before use. Silica is the most commonly used filter medium, but it is very expensive.

## **Aeration**

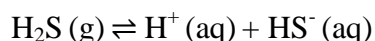
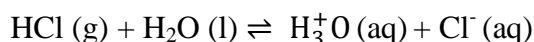
The model diagram of water purification at household level (see Appendix 4) is situated above ground to allow enough oxygen for aerobic respiration in the covered and vented sand, carbon and chlorination chambers. Water is applied evenly across the surface of the sand filter by flooding occasionally to allow oxygen to diffuse. Aeration adds oxygen to the water and allows ionic gases such as hydrogen sulphide, ammonia and volatile organic compounds trapped in the water to escape. Contaminant metal ions such as  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$  are oxidised into higher oxidation states of +3 and +7, which precipitate out of grey water:







In a hydration reaction an ionic polar gas molecule such as hydrochloride gas ( $\text{HCl}(\text{g})$ ) or hydrogen sulphide gas ( $\text{H}_2\text{S}(\text{g})$ ) dissolves in water, resulting in hydrolysis of water, and this leads to formation of hydronium ions ( $\text{H}_3\text{O}^+(\text{aq})$ ). Ionic substances dissolve because of hydration, for example:



These reactions are reversible, and aeration may cause dehydration as the concentration of oxygen increases in the equilibrium system forcing the release of the impure gases ( $\text{HCl}$  and  $\text{H}_2\text{S}$ ) from the water as equilibrium constant shifts to the left.

### 2.4.3 Stage 3: Carbon-filter chamber

Any odour or taste in the water is removed mostly as the result of adsorption or absorption of waste particulates through treatment of water by activated carbon. Absorption occurs when partial chemical bonds are formed between adsorbed species (adhering to the surface of a charcoal) or when the absorbate enters the passages of the charcoal. Charcoal is made up of very small particles that are amorphous and consist of micro crystallites of graphite. The crystal structure of graphite is made up of layers of hexagonal networks, piled on top of each other. Waste molecules of water adhere to the porous channel surface of charcoal. Charcoal absorbs a wide range of water contaminants that include coloured organic particulates to inorganic metal ions such as  $\text{Cu}^{2+}$  and  $\text{Zn}^{2+}$ .

Carbon is activated through a special process at 1200 K using an oxidising agent that selectively oxidises its portions and causes formation of pores in the activated carbon. Because of the special process used to produce these materials with high surface to mass ratio, they are called activated carbon rather than activated charcoal. Factors affecting the absorption of contaminants onto the surface of the charcoal or activated carbon are particle size, surface area, pore structure, acidity or basicity (pH), temperature and the chemical composition of the contaminant to be absorbed.

Alternative LAM that can be used for absorption of waste in water at household level include charred bones and charred vegetation.

#### 2.4.4 Stage 4: Chlorination chamber

The filtered water is then disinfected with one of the following reagents: chlorine gas, chloramine, sodium hypochlorite, chlorine dioxide, ozone. Ultraviolet light may also be used.<sup>5</sup>

Chlorination of filtered water deactivates and kills most pathogenic organisms (e.g. bacteria, fungi and viruses). Disinfection by chlorination is effective in preventing the spread of waterborne diseases such as typhoid and cholera. Chlorine kills slime bacteria moulds such as algae amoeba (see Figure 2). At household level, liquid sodium hypochlorite (bleach) or solid calcium hypochlorite can be used to purify water. Bleach may be used for emergency disinfection at the rate of 2 drops of 5% bleach per litre.<sup>6</sup>

**Table 3: Germ inactivation for chlorinated water (World Health Organisation, 2010)**

GERM	TIME
E-coli bacterium	Less than a minute
Hepatitis A Virus	About 16 minutes
Giardia Protozoan	About 45 minutes

Disinfection of germs depends on the concentration of chlorine and the time needed for the reaction to occur with the pathogen (the contact time), (Table 3). During shock chlorination, a large amount of sodium hypochlorite is added to water. As concentrations of chlorine decrease to parts per million (ppm), water tastes pleasant for drinking purposes.

#### Chemistry of chlorine as a disinfectant

<sup>5</sup> There are many different types of disinfectants, which are used to kill pathogens in water, but for the purpose of this study in line with curriculum requirements, learners to disinfect water used household bleach. [Online]. Available at <http://building.en.wikimiki.net/en/public works>].

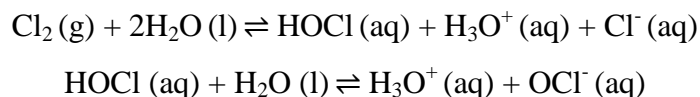
<sup>6</sup> The treatment of water at household level using bleach is done according to treatment table in the US EPA document for Emergency Disinfection-[<http://www.epa.gov/safewater/faq/emerg.html> Emergency Disinfection], and a sample of that table with only three examples of pathogens is shown on Table 2.

Chlorine is one of the most abundant naturally occurring reactive elements in group 17 in the periodic table (i.e. halogens). Chlorine is a very effective disinfectant that reacts with most ions in aqueous solutions, bio- molecules and cell walls of microbes, tissues of small animals and plant material in water. Chlorine kills pathogenic organisms by breaking the chemical bonds of bio-molecules such as enzymes in their bodies. When bacterial enzymes or other cells are exposed to chlorine, one or more of the hydrogen atoms in the protein molecule (enzyme) are displaced by chlorine, causing the entire molecule to disintegrate ( change shape), leading to death.

A weak acid called hypochlorous acid (HOCl) is formed when chlorine is added to water. This process is called the chlorination of water and is described below:



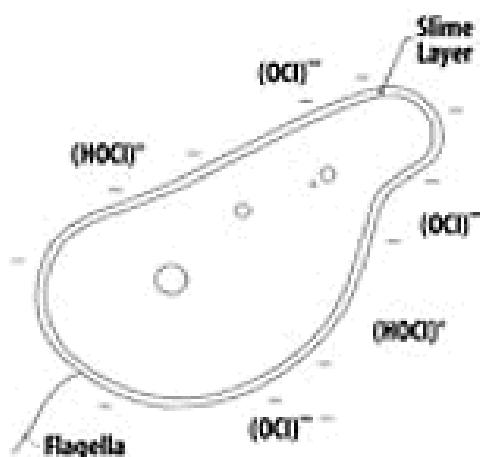
Depending on the pH value, particularly in acidic pH just below 6, hypochlorous acid partially dissociates to hypochlorite ions:



Hypochlorite ions dissociate to chloride ions and active oxygen atoms:



Hypochlorous acid molecule (HOCl), which is electrically neutral and hypochlorite ions ( $\text{OCl}^-$ ), which are electrically negative will form free chlorine when bound together. This leads to disinfection.



**Figure 2: Disinfection of pathogenic microorganism**

Hypochlorous acid is more reactive and is a stronger disinfectant than hypochlorite ions. Hypochlorous acid is split into hydrochloric acid (HCl) and oxygen atom (O) that is also a powerful disinfectant. The cell wall of pathogenic microorganisms that are negatively charged can be penetrated by the neutral hypochlorous acid, rather than by the negatively charged hypochlorite ion. Hypochlorous acid can penetrate slime layers, cell walls and protective layers of microorganisms and kill them (Figure2). The effectiveness of disinfection is determined by the pH of the water. Disinfection with chlorine will take place optimally when the pH range is between 5,5 and 7,5. Hypochlorous acid (HOCl) reacts faster than, and is 80%–100% more effective than hypochlorite ions (OCl<sup>-</sup>) The concentration of hypochlorous acid will decrease when the pH value is higher. With a pH value of 6 the concentration of hypochlorous acid is about 80%, whereas the concentration of hypochlorite ions is about 20%; the opposite is the case when the pH value is 8. When the pH value is 7,5, concentrations of hypochlorous acid and hypochlorite ions are equal (Kunimoto, Masayuki, Shunji et al., 1998)p.69..

It is clear that an understanding of the conceptual framework of constructivism within the chemistry pedagogical content knowledge (CPCK) of Grade 11 learners would develop a scholar who is competent not only in chemistry as subject matter but who also understands learners' difficulties in comprehending chemistry and how to solve them.

## 2.5 Conceptualisation of LAM through improvisation

Many scholars, particularly those in Nigeria have defined the term improvisation in a variety of ways, and like the vague definition of scientific inquiry, there appears to be no scholarly consensus regarding its precise terminology and usage in science pedagogy. For example, Alonge (1979) conceptualises improvisation as an adaptation or modification of the traditional practical materials so that they can perform new functions in the laboratory. Alonge (1983) views improvisation beyond making the substitution of imported or traditional materials, but considers it as a practice that promotes interest, readiness, survival and commitment; all of which are crucial for science, scientists and holistic learning.

Eshiet (2001) defines improvisation as the finding, collection and use of appropriate material for science pedagogy to achieve intended purpose of interest against a background of scarcity or lack of traditional practical infrastructures. Teachers have to hunt for them [instructional materials] so that meaningful teaching of chemistry can take place in the classroom (see Table 4). Olarewaju (1994) asserts that improvisation is the practice of teaching sciences using materials or resources from the local environment. Bajah (1991) defines improvisation as use of alternative apparatus in the absence of the actual or traditional apparatus. Johnson (1994) observes improvisation as the practice of dynamic thinking that can produce tangible output. Teaching materials are learning materials that facilitate pedagogy by helping the teacher to impart meaningfully during the lesson. According to the National Teachers Institute (NTI, 2007) cited in Lowe (1983) they [improvised materials] are also known for their appropriateness, low cost instruments that are normally integrated into pedagogy to improve on conceptual understanding of learners classroom activities or in any other similar environment of formal pedagogy. According to Gilbert, Justice and Arsela (2003) improvised materials such as simulations in science pedagogy function as link between concept of science and the real world experiences “the reality”. Harrison and Treagust (2000) sum it up that the thought of improvisation can be compared to the use of similarities in simulations to improve on understanding of learners’ experiment and interaction.

In short, improvised LAM for teaching are designed and developed to give learner openness or autonomy when engaging in classroom chemistry activities. Teachers are encouraged to improvise LAM in the absence or shortage of practical infrastructures in classroom settings. Improvisation is an innovative concept that can be integrated into teaching chemistry because

it gives learners the autonomy to experiment with LAM available in their local environment. In this study improvisation was expected to provide the grade 11 participant learners with more autonomy (openness) in learning when they engaged in classroom activities (investigations) on chemistry of water purification.

The topic Water Purification include chemistry that deals with learners' everyday life experiences of water scarcity and quality, and using improvised LAM they [learners] will have greater autonomy and motivation to conduct inquiry tasks on the topic in classroom settings. In this research, improvisation is important only if learners are given greater autonomy particularly in the design, methodology and construction of the prototype water purification devices when they are conducting their research.

Improvised LAM became appropriate when teaching chemistry of water purification to grade 11 physical sciences learners for the following reasons:

- Relates concepts of water purification, water impurities and physico-chemical properties of LAM, particularly in the filtration process of grey water.
- Reduces learners' difficulties in understanding of the abstract stages of water purification as they become visible during the water purification experiments, and this will improve on conceptual understanding of learners' activities on chemical reactions [equations].
- Offers learners greater autonomy in engagement of classroom activity because they are given opportunities to interact with common LAM, and to improvise such LAM using their own hand skills.
- Low cost and affordable for learners and the teacher, particularly in the rural communities of Limpopo Province in which this study was conducted.

Table 4 shows the improvisation of LAM as alluded in section 2.4 in the literature review of the chemistry of water purification.

**Table 4: Improvisation of LAM**

Process	LAM	Type of water impurities	Properties of LAM	Improvise d LAM	New function of improvise d LAM	Chemical reasons for function	
Filtration	Fine sand	Solid particles of all sizes	Particle size , 0.25-0.35 mm (smallest)	Fine top sand filter bed	Forms last layer (top) of filter the bed. All solid particles including smallest removed in this layer	For physical treatment of water filter should be stable; because water is polar covalent molecule	
			Sand silt	Particle size 0.45 mm	Forms middle filter bed		
			Gravel or granite stones	Particle size about 1mm (largest)	Forms the first layer (bottom) of filter bed		
Other examples of LAM that can be used at household level are crushed glasses and mineral pieces. All filter media should have constant composition, uniformity, neutral pH, low cost,							

and be hard and insoluble in water. Silica is the ‘original’ filter media, but very expensive.

<b>Carbon filtration</b>	Charred bones and charred vegetation, bottom ash		Filter should have large surface area, open pore structure, neutral pH, high temperature resistance		Adsorption of chemical impurities; removes any odour or taste in the water	Adsorbed contaminants adhere to surface or absorbate enters passages of charcoal
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Adsorption also depends on the chemical composition of the contaminant to be absorbed and its particle size including properties of carbon filter mentioned above. The ‘original’ carbon filter is activated carbon or charcoal, but very expensive to produce-special process at high temperature causes formation of pores during oxidation.

<b>Chlorination</b>	Bleach Liquid sodium hypochlorite or solid calcium hypochlorite	Pathogenic organisms: bacteria, virus, fungi, algae amoeba etc	Very reactive, effective disinfectant and strong oxidising agent	Bleach: 2 ml or 2 drops bleach per litre of filtered water	Kills pathogenic organisms:	Chlorine reacts with most ions in water, bio-molecules, tissues, cell walls
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Marsh water bottle: collection of grey water



3 litres muddy or grey water: for filtration
Two empty cooking oil plastic bottles (2L each): one funnel (bottom cut off), other for sedimentation (top cut off)
1000 ml glass bottle: collect filtered water ready for disinfection by liquid bleach
5 litres of clean from boiling: to wash off and clean layers of bottle filter bed and prevent filter media from being blocked by impurities.
Tea leaves sieve filter or cotton cloth: filtration of solid impurities
Elastic band: tighten cloth filter to neck of filter bottle that has bottom cut off

The ‘original’ materials or ‘real things’ that the teacher has to find in the laboratory or purchase are:

- electrolytes either alum or lime for precipitation of metal ion contaminants in water (coagulation)
- litmus paper or universal indicator for testing pH of water
- Clock or wristwatch with a second hand to measure rate of seeping of water in the plastic bottle filter during process of sedimentation and filtration

Stiggins (2008) notes that there is a wide range of approaches to teaching that can be applied to improve active learning and learner performance in class. An approach to teaching chemistry of water purification via SI that integrates improvised LAM could also complement them [teaching approaches]. However, for an improvised LAM to be appropriate, the material should provide learners with greater opportunities for openness or autonomy when they are engaging in activities on chemistry of water purification. The material should also improve on the conceptual understanding of learners’ concept of water purification when learners visualise chemical reactions that clarify water they should be able to link the physico-chemical properties of LAM and water impurities. The LAM should not

pose health risk to users and this should be taken as a good reason for improvisation in the learners' research on water purification.

Aina (2012) cautions that almost all of the improvised materials are unreliable in terms of accuracy and precision in measurement, and this can actually undermine the implementation of pedagogy. However, Fakunle (2010) asserts that improvised teaching materials improve learner's curiosity when appropriately applied during teaching. Adeniran (2006) note that active learner participation and materials for improvisation that come from their own areas offer them opportunities for motivation, advancement and inventiveness; all of which are crucial for science pedagogy.

Improvised materials provide an alternative to the original, which by virtue of their source meet the learning needs of the learner in terms of cognitive behaviour because learners are already familiar with the materials from their own local surroundings. Improvised materials are appropriate for science teaching because they make the learning process to be interesting, and learners understand concept through intrinsic motivation and this reduces the memorisation of theory or concept. Many scholars have studied the significance of incorporating teaching material [improvised material] for learners' achievement in mathematics and science. For example, Rode (1995), Rogerson and Cheney (1989) note that in molecular genetics diagrams alone could not fully describe the concept whilst simulations developed by learners actively engaged them and improved on their conceptual understanding of topic. Usman and Adewunmi (2006) investigated factors that incapacitate teachers to improvise teaching materials for mathematics. Domnwachukwu and Domnwachukwu (2006) investigated the effectiveness of substituting LAM in teaching chemistry in Nigerian classrooms and found that there were similarities in results for titrimetric experiments conducted by the group of learners who unknowingly used chemical extracts from local plants and a group that knowingly used processed laboratory chemicals.

In Africa, a number of scholars have carried out research studies related to the application of LAM on the pedagogy of science in classrooms. If learners learn chemistry using problem solving approaches like SI that integrates LAM with which they are familiar, learning will be easier, more meaningful and relevant, such as is the case in Japan, India and South Korea. These countries have all been successful in teaching sciences using LAM (Domnwachukwu & Domnwachukwu, 2006). In Africa literature dealing with science pedagogy contains many

examples of classroom activities that incorporate materials from the local environment as substitutes for processed laboratory materials especially in chemistry experiments, but not much has been documented on the use of LAM using SI in teaching water purification as a research topic. Domasi: Malawi Institute of Education (Byers, 2002) produced a module on a TALULAR, a term that means teaching sciences in schools using LAM. Teachers designed and developed students' research projects and practical investigations using LAM. TALULAR also translated science into technology using indigenous scientific knowledge systems to promote Science and Technology in Society (STS). Womack (1995), in his programme of In-Service Training and Assistance to Namibian Teachers (INSTANT) using science kits and LAM, acknowledges that "most textbooks and science experiments seemed patently irrelevant in these remote schools; teachers and learners just wanted to know 'How does it work?' or 'What to do with it?'" According to a compilation of research papers by Maake and Cronje (1999), The Witwatersrand University Research and Development in Maths and Science and Technology Education Centre (The Wits RADMASTE CENTRE) (1991-1994) workshops provided experience in the improvisation of LAM in the absence of traditional science equipment. However, [Maake & Cronje] reported that these practical sessions were poorly managed, frustrated learners and were unpopular. Therefore, specifically an existing opening in the literature motivates this study, as there is a paucity of research on SI instruction integrating LAM and learning in Grades 10–12 in Limpopo Province, worse still there are appears to be no studies on research projects such as chemistry of water purification

### **2.5.1 Water experiments (IYC, 2011): Improvisation of LAM in teaching Water Purification**

The present study was concerned with using LAM to solve Grade 11 learners' difficulties in understanding the chemistry of water purification in classroom instruction. As noted earlier, neither the NCS nor the CAPS documents provide methodologies for teaching integrated topics such as water purification. The teacher's role is thus to facilitate a literature search through teaching the chemistry of water purification and to assist learners in identifying LAM that can be used to remove impurities from water. The adaptations of practical activities in water experiments, particularly from the manual of International Year of Chemistry (IYC 2011, p.p.1-3) facilitated learners' comprehension of water purification, more so that the essential aspects of the Grade 11 chemistry curriculum such as the difficult concepts of acid-

base systems, redox reactions precipitations, pH dependent equilibria and quantitative (molarity) stoichiometry of chlorination were preserved in the research topic Water Purification. The Global Experiment of the IYC (2011) offers laboratory investigations to test the physico-chemical aspects of water and purification of water using a solar still and filter media. According to *Chemistry: All About You – Module 6. Hands on activities: Water experiments* (IYC,2011, p.p.1-3), students will use *household materials*, which in this study are referred to as LAM, to build *a water filtration unit*, in this study *a simple water purification system and water purification device for use at household level*. The household materials that will be improvised to enable the teaching of the topic and that learners will use in the procedure for the water purification experiment are: (see lesson 1, Appendix 7):

- 3 litres muddy or grey water or from a muddy pool containing sediments of clay, sand ,silt, gravel including solids such as dead remains of plant and animal life and organic and inorganic contaminants
- 5 litres of clean water readily available from boiling to clean the layered bottle filter bed made of fine sand, silt sand and gravel stones in that sequence from top to bottom
- Two empty cooking oil plastic bottles of volume two-litre each, one with its bottom removed to use as a funnel for pouring water into a container and the other with the top removed for use in the sedimentation process
- one large, wide opened cooking oil 1000 ml bottle or 1000 ml glass bottle used to collect filtered water ready for disinfection by bleach
- tea leaves sieve filter or cotton cloth for filtration of solid impurities, and elastic band to tighten cloth filter to neck of filter bottle that has bottom cut off , 700g fine sand filter media of size about 0.25-.035 mm, 700g coarse sand silt filter media of size about 0.45 mm and 500 g gravel stones filter media of size about 1mm used to remove solid contaminants during process of sedimentation and filtration
- processed electrolytes either 10g of alum ( $\text{Al}_2 (\text{SO}_4)_3 \cdot 12 \text{H}_2\text{O}$ ), or 10g lime,(  $\text{Ca} (\text{OH})_2$ .) which (increase the pH) when added to water coagulation takes place, and flocs which trap dirty particles by adsorption are formed. Metal ion contaminants of iron

and aluminium precipitate out of water as dirty particles, and this makes grey water clear

- litmus paper or universal indicator for testing pH of water
- spoons for lifting alum and mixing grey or muddy water in the plastic filter bottle bed
- stopwatch or clock with a second hand to measure rate of seeping of water in the plastic bottle filter bed
- marsh water bottle for collection of dirty water from muddy pool or kitchen sink
- 2 ml or 2 drops of 5% domestic liquid sodium hypochlorite (bleach) per litre of water, or similarly 2g solid calcium hypochlorite to disinfect filtered water.

Alum (for coagulation process) and litmus paper or universal indicator (for testing water pH) are the only processed chemicals required to carry out this practical activity, used as chemical tools to clean water through coagulation.

## **2.6 Difficult nature of chemistry, water and water purification**

Water is said to be one of the basic stuff of life, and without it, life would be impossible on earth. Water links all biotic and abiotic components of the earth as an ecosystem from the sub-microscopic (molecular) level to the universal level. Brody (1993), in his literature review on the students' understanding of water concepts, asserts that learners' knowledge of water is hard to do a literature search and analysis because of the integrative approach of the topic. The interdisciplinary nature of the concept of water that includes aspects of physics, chemistry and biology makes it a difficult topic for many learners to comprehend because it covers many different integrated concepts within one topic. For example, physical chemistry describes the physico-chemical properties of water that are related to its polarity such as structure, conductivity, solubility and molecular bonding that leads to its unique properties, more important the hydrogen bonding. In chemistry, the function of water is unique because all life processes that comprise process of metabolism take place in aqueous solutions, and so is solution chemistry at laboratory and industrial levels. In biology the interdependence of living and non-living components of the earth, including trophic levels are linked to water as the most important stuff in life that drives ecosystems. According to Brody's (1993) analysis of literature related to water and water resources, many scholars generally focus on aspects of

physics and chemistry that tell a lot of student misunderstanding, which in turn reflects learners' problems in kinetic theory of matter among other misunderstandings. Many scholars have conducted research studies to investigate learners' perceptions and knowledge that relates to states of matter within the context of heat and temperature particularly for water (e.g. Osborne & Cosgrove, 1983; Straus, 1987; Rafel & Mans, 1987) and pressure (Giesse, 1987). Osborne and Cosgrove (1983) describe the "use of interview-about-events" methods that demonstrate learners' perceptions on related concepts such as evaporation and condensation. They found that most learners who were attending science classes in the age group 8 to 17 years gave answers that had no clue in their descriptions about the concepts of phase changes of water being taught. Instead, learners often referred to "the bubbles that form when water is boiling as gases such as air, oxygen, or hydrogen gases." This means that most learners in schools have misconceptions about water related phenomena such as kinetic theory of matter and physico-chemical properties of water for example solubility, evaporation and condensation, that are basic to further understanding chemistry concepts in higher grades. Osborne and Freyberg (1999), assert that students' failure to describe physico-chemical phenomena linked to water and states of matter might be due usually to invisible chemical processes such as ionisation. In the light of these studies, it is manifest that students' hold alternative conceptions on the particulate nature of matter particularly the interface between atoms and molecules within thoughts of kinetic theory of matter, and this in turn is directly linked to their misunderstandings of the physico-chemical properties of water.

Many scholars observe that the abstract nature of chemistry leads to difficulties learners experience with the subject, and that many learners regard chemistry as a difficult subject to learn. According to Abraham, Grzybowski, Renner and Marek (1992) and Taylor and Coll (1997), the source of learners' problems in learning chemistry in the classroom arise from the continuous interaction of particulate, descriptive and representational thoughts of chemistry. Barker and Millar (2000) and Harrison and Treagust (2000) note that students when learning chemistry possess different views and experiences that are often in conflict with learning topic or concept. Tsapalis (2003) and Mahafy (2005) report that learners experience problems in creating mental models of three-dimensional formations of matter as well as to explain interactions of atoms, ions and molecules in chemical reactions, and this leads to learners' inadequate comprehension of a variety of chemical concepts. Therefore, learners' failure to visualise mental models of the particulate nature of matter and the use of traditional

approach of teaching a chemistry topic, might lead to many problems that are linked to misunderstandings of basic chemistry such as “atomic structure and bonding” (McCormick & Li, 2006; Jennings, Epp & Weaver, 2007; Sellers, Robert, Giovanetto et al. 2007; Simsek, 2009). It is therefore important for teachers to identify problems experienced by learners in chemistry before a teaching plan is implemented in the classroom.

## **2.7 Reports of recent research on SI related instruction**

Many different approaches can be used in the pedagogy of teaching chemistry of water purification because different integrative concepts of the topic require different teaching methodologies to complement the SI used in this study. Some of the teaching techniques that can be systematically incorporated into the main SI instruction are discussed here:

**Lecture approach:** This is a traditional approach to teaching science that is linear in sequence. In this approach, the teacher is the specialist and the learner is the trainee. There is a linear transmission of knowledge from teacher at the top to learners at the bottom. Van den Berg et al. (in Vonk, De Feiter and Van den Akker, 1995) note that because of various challenges in developing countries, traditional teaching approaches are given more precedence, and are facilitated through questioning and demonstration in an active collaborative environment. In order for the teacher to simplify the complex concepts of chemistry, he/she has to be resourceful and build supportive learning environment that relates to the social context of the learner by developing relevant instructional material that includes improvised LAM.

**Problem solving:** According to Taconis, Ferguson-Hessler and Broekkamp (2001) teachers using conventional instruction to problem solving give learners many questions to look for answers independently. Duch (1995) describes an approach of problem-based teaching as one that involves societal matters as a perspective within which logical reasoning and knowledge of concepts are learnt. Cardellini (2006) explains that problem solving does not only involve computing figures in formulae of mathematics, but also interacts with innovation and logic in the context of recognised knowledge. According to Poyla’s model (1957) and Nutt (1997), problem-solving process comprises four stages: problem identification; designing or modelling problem; procedure to implement design; and reflection or analysis. These stages are clearly similar to the stages of SI process that will be used to implement the SI teaching approach in this study and these [stages] include teaching

of authentic problem (concepts or knowledge), design, procedure (physical skills in laboratory), collection of data, analysis and inference (presentational knowledge) and finally writing skills (representational knowledge). Learners in this study had difficulty learning the complex concepts of water purification using LAM. Adler (1997) and Franco, Sztajn, and Ortigao (2007) have referred to the term problem-based learning (PBL) as a participatory-inquiry, collaborative or cooperative and learner-centred approach. These learning approaches are inseparably related to SI instruction, and more specifically to the applied hypothetical type of inquiry that was used in teaching participant Grade 11 learners about water purification using a problem-based learning approach (i.e. participatory-inquiry).

**Context based approach:** According to Villalino (2009), the context-based instruction in science is described as an approach that advances scientific concepts through issues in topics and application of science in environment. Belt, Leisvik, Hyde and Overton (2005) argue that context-based instructional instruments should not be used in the main teaching approach; instead they should only be used to facilitate other teaching activities, lest students will be often confused at different times. Teaching approaches are interlinked, and support or facilitate each other when applied in classroom instruction as multiple perspective approaches (Belt et al. 2005; Treagust & Duit, 2008). Most research studies put the learner at the centre of learning. Scholars worldwide are busy focusing on how a learner can learn subject concepts meaningfully in classroom settings, and how a teacher can teach learners how to learn subject concepts effectively. Most instructional designs and materials are attempting to promote active and collaborative learning as embodied in the constructivist learning theory. In these free learning environments, quite contrary to apprenticeship models, the learner assumes role of expert and not a novice and the teacher becomes a “spectator” only guiding the learner from the terraces, and applying these approaches requires a lot of expertise as discussed in the Constructivist learning perspectives in the next section.

## **2.8 The Constructivist Learning Theory**

This study is grounded in the constructivist theoretical framework. According to this theory, a model environment for learning is described as one that offers opportunities to learners to conceptualise knowledge and, to supposedly function as dynamic, intrinsically motivated, self-regulated, and cooperative participants. According to the followers of constructivist learning theory, they accept that learning is an intrinsic factor that involves the active



comprehension of new knowledge built upon learners' current experiences in understanding chemical phenomenon. This idea counters the instructivist or objectivist approach to learning that accepts that knowledge exists impartially of the expert and understanding is placed on preceding experiences.

The two leading philosophies within the constructivist model are personal constructivism and socio-cultural constructivism. Personal constructivists accept that understanding is structured in the head of the learner (Piaget, 1970; Von Glasersfeld, 1989), while social constructivists take that understanding is assembled within cooperative experiences that exist in community of practices (Kuhn, 1996; Vygotsky, 1978). Cobb (1994) claims that the two philosophies are inseparable and facilitate each other. In this study, the author was guided by Cobb's (1994) conception that knowledge can be assembled through social cooperation and theorised in the mind of an individual learner. This implies that socially assembled knowledge is understood and advanced in the learner's mind and linked to his or her past experiences of water purification. Learning environments should support learners' active comprehension of knowledge. In this study, this was achieved by the constructivist perspectives, which offered teaching model and procedure through SI instruction that applied LAM. However, it should be mentioned that there is not one single way of conceptualising learning systems.

### **2.8.1 The learners' task**

According to Von Glaserfeld (1984), learners create understanding. In this study, learners did not simply duplicate what they were taught but they searched for meaning in the term “water purification” and tried to find pattern in the concepts of chemistry related to topic. This led them to develop prototype devices for water purification at household level using LAM, even though they did not have access to all the relevant information and traditional laboratory materials (Appendix 9).

### **2.8.2 The art of understanding**

Woolfolk (1993, p. 485) describes the constructivist notion of the learning process as “active”; the main belief is that learners dynamically create their own understandings. Ertmer and Newby (1993, p. 63) suggest that the purpose of teaching is to offer learners with a cooperative environment that gives them facility and opportunity to organise “new and situationally specific understandings by assembling prior knowledge from diverse sources”.

The two aspects that are important in characterising these constructivist explanations of the learning process are: authentic scientific problems (water purification) and cooperation (teamwork or group work)

According to Brooks and Brooks (1993), constructivist teaching approach presents an authentic but complex scientific problem that challenges learners to generate and experiment hypotheses; and can be solved by simple and cheap materials, and is settled through team work as learners interact through sharing knowledge and skills. In cooperative environments learners work as peers, and the discourse that results from their mutual understanding offer them the opportunity to analyse and process their understanding in the project they will be undertaking.

### **2.8.3 The job of the teacher**

Vygotsky's (1978) model of learning through socio-cultural interactions enhances intellectual growth of learners, and differs from Piaget's (1978) personal approach to understanding knowledge. According to Rice and Wilson (1999) his [Vygotsky's] abstract model of the zone of proximal development (ZPD) represents his conviction that social growth and learning are linearly linked. Vygotsky's mental conception for the process through which social collaboration facilitates learning is similar to apprenticeship simulations, in which the work of a trainee is closely supervised by an expert as they work together through dialogic discourse in the zone of proximal development. In this model, the trainee gets assistance in those critical skills and activities that he or she is unable to perform alone. In his analysis of apprenticeship simulations Rogoff (1990, p. 7) observes that learners are considered as trainees who acquire skills and knowledge from participating with experts within the paradigm of socio-cultural activity.

According to Brooks and Brooks (1993) a constructivist teacher, among other functions is envisaged to:

- let learners work independently, for instance in the project of building a simple water purification device using LAM.
- assist learners to use a wide variety of affordable materials, for example LAM that was used to clarify grey water in the design and construction of the future device.

- investigate learners' problems in learning topic, in this case chemistry of water purification before starting lessons.
- support learner inquiry by asking flexible investigative-type of questions and also allow learners generate questions amongst themselves.
- offer time for learners to build connections between concepts in a topic, for example learners will have to think out connections between chemistry of water purification, water impurities and LAM.

#### **2.8.4 Constructivist learning environments**

Bednar, Cunningham, Duffy et al. (1992) argue that the designer must first master the concepts underpinning the model in order to produce a productive teaching model and development has to be grounded in some conceptual framework of pedagogy.

Lebow (1993, p.p. 4-16) notes that:

...traditional educational technology values of replicability, reliability, communication and control (Heinich, 1984) contrast sharply with the seven primary constructivist values of collaboration, personal autonomy, generativity, reflectivity, active engagement, personal relevance and pluralism.

In both constructivist and traditional perspectives the key in designing and developing an effective instruction lies in educational thoughts such as cognitive knowledge, the learner and the teaching environment that are in constant interplay. Procedural Identity (ID) models “describe how to perform a task and are formulated to simplify and explain a series of complex processes” (Bagdonis & Salisbury, 1994, p.p. 26-32). The ID models in the instructional systems design field (ISD) attempt to consider all significant steps using a logical approach to designing a teaching approach starting from essentials of evaluation to construction of teaching tools through the, application of these tools in a classroom to assessment of learners. Traditional ISD models usually comprise successive and distinct steps that follow a one-way sequence in five phases: analysis, plan, construction, application, and continuance or review. (Bagdonis & Salisbury, 1994).

Willis (1995) reviews the traditional Objective-Rational Instructional Design model that comprises eight aspects:

1. one-way and progressive the strategy is followed

2. organisation is logical and from top to bottom
3. aims drive progress
4. specialists, should possess exceptional competencies that are important to identity tasks
5. thorough organisation and instruction of basic skills is critical
6. transfer of the prescribed knowledge defines the purpose
7. cumulative assessment is essential
8. impartial knowledge is important.

This model is still very popular in schools, and has not yet been eroded by the passage of time in the history of education. Teachers still use traditional didactic approaches in classrooms, despite calls from a variety of studies to use alternative instruction such as SI that is guided by the constructivist learning theory. The major reason might be lack of teachers' knowledge about SI instruction and constructivist learning ideas, teachers' incompetence in pedagogical chemistry knowledge and poor practical infrastructure in schools. Of particular interest in recent years is the emergence of rival models in the context of constructivist learning perspectives. In his analysis of the literature on instructional design models, Willis (1995) provides a rival model to the traditional Objective-Rational ID model which he named the Constructivist-Interpretivist Instructional Design Model that has the following aspects:

1. Planning strategy is repetitive, non-linear, and at times disordered.
2. Organisation is natural, developmental, analytical, and socially cooperative.
3. Aims originate from plan and progressive tasks.
4. Broad identity specialists are absent.
5. Teaching approach promotes personal understanding and is context-based.
6. Formative assessment is important.
7. Personal or particular knowledge could be most critical.

It is assumed that these constructivist design principles can lead to a variety of constructivist learning environments such as situating cognition in real-world contexts, cognitive flexible learning, collaborative learning, etc., that would be crucial in the actual implementation of the teaching plan in this study. According to Brown, Collins and Duguid (1989) situated cognition proposes that knowledge and the circumstances of its application in environment are inseparably interlinked. Jonassen (1991) asserts that learning occurs meaningfully in a perspective that connects source of knowledge and real life experiences related to learning. In a related teaching approach, Cognition and Technology Group at Vanderbilt (1992) underscore the need to integrate skills and knowledge into real life situations. Similarly, in

apprenticeship models as learners carry out proficient work they increase their knowledge, practical or investigative and strategic skills through training (Collins, Brown & Newman, 1989), and problematic question-oriented learning theoretical representation (Barrows, 1985, 1992) and scenario-oriented learning in which students participate in solving relevant activities. Introduction of multiple perspectives to learners is very crucial because they must consider a topic, for example, chemistry of water purification from a variety of thoughts, more so its interdisciplinary nature requires an integrative approach to pedagogy, and this complicates learner understanding. Within the paradigm of constructivism of learning environments, learners are encouraged to choose the most appropriate perspective as they attempt, in the process to understand other perspectives (Bednar, Cunningham, Duffy & Perry 1992). In order to avoid superiority of a single teaching approach, flexibility theory emphasises understanding conceptual connections, variety of teaching approaches on cognitive content, and case-based instruction that offers a variety of aspects in the cases (Spiro, Coulson, Feltovich et al. 1988). Cooperative learning environment is crucial in constructivism particularly in environments such as flexible learning, multiple perspectives and situated learning. Bednar et al. (1992) argue that cooperative learning provides learners with opportunities to master diverse representations of a problem and share tasks. The purpose in cooperative learning involves the difficult task of developing and assessing logical thinking.

## **2.9 Summary of Literature Review**

This chapter discussed a number of previous studies that have provided a theoretical background to SI as an instructional approach. SI was defined and contextualised as four types of knowledge. The pedagogical chemistry content knowledge of water purification that will lead to the development of activities in the next chapter was provided. Some prospective strategies for teaching the chemistry of water purification using the SI approach were presented. In addition, the contribution of the study was underlined in its integration of LAM in the SI instruction approach. Finally, the theoretical constructivist framework was discussed as an instructional design for the crucial teaching strategy in Chapter 3 and for data analysis in Chapter 4.

## **CHAPTER 3: RESEARCH DESIGN AND RESEARCH METHOD**

### **3.1 Research Design**

#### **3.1.1 Mixed-method research**

The researcher used mixed-method research within which the pragmatic aspect investigated the effect of a SI teaching approach that integrated LAM and compared it to the traditional teaching approach in the teaching of the topic of water purification. James Dewey and George Herbert Mead are the first two American thinkers who popularly advanced and promoted pragmatism as a philosophy that involves critical thinking (Dewey, 1960; Mead, 1981). It [pragmatism] is concerned about empirical work and has no dispute endorsing either the positivist, who thinks in a practical world, or the constructivist who believes in a socio-culturally built world. According to these thinkers, a useful model is one that enables people to achieve a particular target as well as reduces doubt about the results of an event (Halton, 2004; Peterson & West, 2003). For the purpose of the research design of this study, pragmatism deals with investigation of Water Purification, an empirically feasible research task that is realistic in nature and that simply works to provide learners with results that help them to solve problems of water contamination at household level using LAM. Most pragmatic scholars use a “mixed-methods” research that comprise qualitative and quantitative approaches of data collection to analyse the same action; and this idea was first presented by Campbell and Fiske (1959).

The use of mixed mode research:

- considers the merits and demerits of both quantitative and qualitative research. For example, quantitative research is thought to be incomplete because participants’ voices that result from dialogic discourse of problems are not considered in the analysis of findings. Qualitative research is limited because of the scholar’s personal feelings in explanation, in preconception as well as in oversimplifying findings. However, qualitative research reduces these inadequacies as observed by Brannen (2005).
- provides all-inclusive information for more analysis of a research problem than quantitative or qualitative research alone.

- is empirical because the scholar can apply all methods appropriate in dealing with a research question and that includes both numbers and words, thus combining both inductive and deductive thinking.

In this study, qualitative data provides cognitive knowledge of the difficult nature of the chemistry of water purification from the active teamwork, perspectives and transformation of of learners' experiences so that it [qualitative data] can address the causal inferences and descriptions of chemical phenomena, complemented by the quantitative data as observed by Eisenhardt (1989) and Mason (2006).

Therefore the data in this research was collected mainly through quasi-experimental means that compared SI instruction integrating LAM with traditional instruction, supported by the qualitative data obtained from interviews and questionnaires dealing with concepts of chemistry of water purification and LAM.

### **3.1.2 Quantitative methods of data collection (Quasi-experimental design)**

The study constituted an empirical inquiry that investigated the instruction of chemistry of water purification that integrated locally available materials (LAM) within real life contexts. The study employed case methodology guided by mixed-method research, consisting of qualitative and quantitative methods of data collection. Within this approach a quasi-experimental non-equivalent pre-test – post-test control groups design was applied (see Table 5). The design addressed question 2 (sub section 1.1.5) that examined the difference in performance in classroom activities and tests of two groups of learners who were taught chemistry of water purification processes using LAM by SI and traditional teaching respectively. Confusing variables also known as third variables or mediator or external variables are described as those threats in the form of events ,objects or conditions that the researcher fails to control, or eliminate, and can cost the internal validity of an experiment. These external variables can negatively influence the interaction between the independent variable and dependent variable and result in a fallacious association between the two variables. In this study, the design does not allow complete control of external threats (variables) such as limited time to conduct the research, inadequate support in terms of materials and apparatus and teachers' lack of knowledge about processes of SI. Another external threat is that the design uses experimental groups A and B and control groups C and D that are different in respect of learning abilities of participants and their past performances

in classroom chemistry. These two groups are not equivalent in respect of influencing the performance of students in post-test and rubric assessment task, which are the dependent variables in this study. The uncontrolled variables operate as rival or competing hypotheses, as observed by Becker, Rabinowitz and Seligman (1980). Nevertheless, the design is appropriate to educational studies such as this research when inferences for observed effects of teaching the topic using LAM are desired. In this study competing hypotheses were eliminated by both the use of precise (small intact classes) control groups C and D in the experiment and rigorous operationalisation system that strictly defined Scientific Inquiry, Water Purification and LAM (independent variables) and learner performance in post-test, RBT2 and post-response, RAT (dependent variables) into measurable aspects.

Becker et al. (1980) used quasi-experimental control groups design in their social studies of causal effects and obtained the following results:

- escalating intervention effect only, experimental group better and control group worse
- escalating intervention, all groups improve but experimental group performs relatively better than control group
- escalating intervention effect only, experimental group worse and control group better
- crossover effect represents intersection point that is critical for both experimental group and control group.

In Campbell and Stanley's (1963) study, participants were not randomly sampled to the groups owing to constraints associated with the empirical nature of the study. In this study similar sampling was used because of limitations such as the unavailability of some processed laboratory materials (e.g. litmus paper/universal indicator, alum and lime) and short time to conduct classes and practical activities. In addition this sampling technique was experimented in this study in order to use small intact classes that did not disrupt the normal classes, as advised by the circuit manager of Malamulele Central (Appendix 11). In order to avoid contamination of the control groups, the intervention in the experimental groups was carried out in different schools some distance from the control group schools so that learners could not share information with each other on a daily basis.



**Table 5: The research design of the study**

Groups	Pre-test	Treatment	Post-test
Experimental (EG)	T1 T2	X1	T1 T2
Control (CG)	T1 T2	X2	T1 T2

Compare

In Table 5, the experimental group (EG) used the SI approach (X1), while the control group (CG) used the traditional approach (X2). T1 = Research-based Test 2 (RBT2), T2 = Rubric Assessment Tool (RAT). Pre-post-tests of EG were compared with those of CG by effective pairing of similar participants across groups.

A quasi-experimental control groups design has the following advantages as it provides:

- descriptive evidence on those learners receiving intervention through SI instruction.
- information that means that teaching through SI produces predicted positive results of higher performance in experimental group. If this is not so, the scholar should review variables that may obstruct the expected effects from occurring. (Shadish, Cook & Campbell, 2000).
- data that show the statistical significance of mean scores that is occurring over time through SI instruction compared to effects resulting from traditional instruction as observed by Reed and Rogers (1999). The relative effects of the mean scores of the two groups over time can be ascribed as large, medium, small or not at all based on the significance of statistical evidence.
- information on whether the predicted effects are more efficacious in some sub-groups than in others; therefore a quasi-experimental design enables scholars to characterise the magnitude of SI intervention results [learners' performance scores] of learners and compare them to those of learners who use conventional learner-centred approaches of learning as described by Gall, Gall and Borg (2007).

## **Tools for statistical analysis of data**

In order to address research question 2, three statistical principles compared the effects of SI instruction to traditional instruction. Assuming that there is no variation and sample is more than 30;  $N=32$ , independent  $t$ -tests compared the mean scores of pre-tests and post-tests of experimental groups A and B and control groups C and D. The analysis of variance (ANOVA) compared the mean scores between experimental groups A and B and control groups C and D; and within experimental groups A and B, and within control groups C and D, on post-test RBT2. Descriptive statistics compared mean scores of experimental and control groups in five sections of rubric assessment tool, RAT on the realisation of the water purification device. GraphPad Instat-3 statistical software (2012) generated graphs and statistical calculations such as means and percentages that analysed and validated the quantitative data from the two research-based tests, RBT1 and RBT2, RAT and learners' activities 1 and 2.

During formal research projects for CASS the scholar initially piloted these class activities in two nearby schools code named E and F. He [scholar] identified problems in this piloting process and refined teaching instruments that were tried in participating four schools code named A, B, C and D. The scholar reviewed the performance of learners and assessed the efficacy of the classroom activities and tests in realising lesson objectives (Appendices 5, 7 & 8).

### **3.1.3 Qualitative methods of data collection**

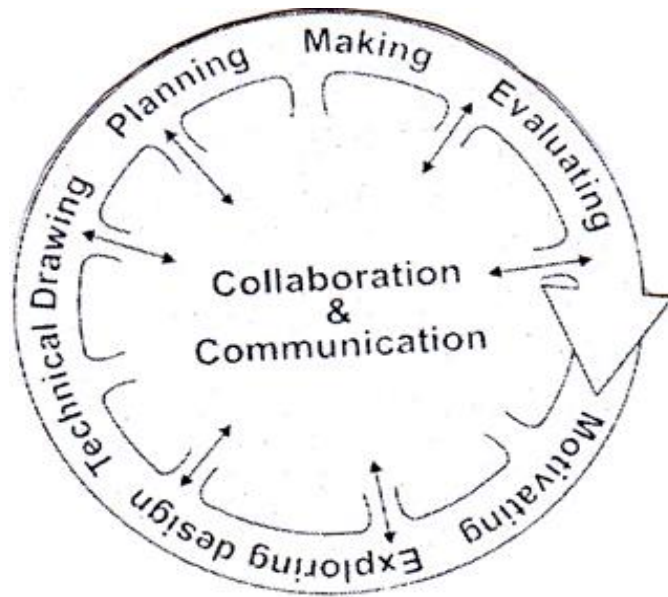
The systematic analysis of different types of data to establish the extent of relationships is a sophisticated process called “axial coding” (Strauss & Corbin, 1990). Owing to the small sample size, “open” coding was chosen in this study to analyse the qualitative data from questionnaires and interviews. Statements emerging from raw data were the classification principal aim. Thus, each script and interview excerpt was recorded, typed, analysed, given meaning and classified to create patterns and trends in order to establish the difficult parts of learning the chemistry of water purification. This created the framework for analysis (see Appendices 1 and 2). Scientific views that appeared to be similar concerning the difficult parts of the topic were grouped together. The excerpts were then read through and grouped into classes. This was achieved by breaking data from learners' interviews and questionnaires into simple and convenient entities, following Brown (1996) and Duffee and Aikenhead

(1992), and arranging these in logical classes so that they could be analysed as a whole. Thus the triangulation of data ensured the validity and reliability of results through matching views of learners from the questionnaires and interviews. According to Andrad (2009), Creswell (2006), Creswell and Plano (2007) triangulation of data that includes a variety of informants for a specific scenario facilitates the collection of abundant information and improves analysis of results. After the questionnaires and interviews had been analysed, the information obtained from learners regarding the chemistry of water purification and how the LAM enhanced learners' understanding of chemistry was documented.

The researcher used this information to design post-test RBT2 on the topic and to develop guidelines in construction of prototype devices for water purification using LAM through an SI teaching approach. The formative assessment was used to revise items in the learners' activities 1 and 2 and post-test (RBT2) during their construction.

#### **3.1.4 Design and Technology Model (D&T)**

The scholar also incorporated into the study a mental simulation of D&T conceptual framework for pedagogy (Figure 3), which focuses on teamwork in order to promote the practicality of the topic in alignment with the perspectives of constructivism. This study was inspired by a pedagogy for D&T concept of teaching and learning approach among middle school learners in India, the “collaboration and communication centred D&T education model” (Choksi, Chunawala & Natarajan, 2006) that was adapted from the UK curricular approach “Design-Make-Appraise” of the Assessment of Performance Unit (APU) (Kimbell, Stables & Green, 1996). This instructional framework proved to be particularly useful to the experimental groups working as a team when they successfully designed and made the prototypes of water purification devices using LAM once they had mastered the chemistry concepts of the topic in classroom activities.



**Figure 3: A model of D&T education centred on collaboration and communication<sup>7</sup>**

In this study, the practical aspects of water purification of D&T teaching and learning units were developed by Grade 11 learners through chemistry classroom activities in four different school settings. Choksi, Chunawala & Natarajan (2006) observe that “the learners contextualised and negotiated the design problem of the device in groups, investigated potential ideas, planned the design and production of the product, actualised their plan, and evaluated the results.” This model is supported by the constructivist perspective that learners construct meanings and understandings of phenomena through teamwork in an active environment (section 2.8). Guided by SI instruction the learners created new understanding and acquired critical skills to defend arguments for their designs, choice of LAM and tools and empirical methods of data collection in line with their research topic.

## **3.2 Research Method**

### **3.2.1 Variables of the study**

The independent variables in this study were Scientific Inquiry, Water Purification and LAM. The dependent variable was learner performance in post-test, RBT2 and post-response, RAT.

<sup>7</sup> Source: Choksi et al. (2006: p.p.274–284). The model inspired the author when one of the scholars who undertook learners’ project based on D&T model in India, presented their work at the UNISA’s Institute for Science and Technology Education International Conference on Mathematics, Science and Technology (October 22–25, 2012) held at Mopane Camp in National Kruger Park of South Africa.

### 3.2.2 Population of the study

Table 6 shows that the total population of Grade 8 to Grade 12 learners of the four participating schools, which were randomly selected from 15 schools in Malamulele Central Circuit, was 4700, with a sample population of 270 Grade 11 Physical Sciences learners, with an average of 68 learners per class and 11 Physical Sciences teachers. The teachers chose grade Grade 11 learners because they had completed the topic of basic aquatic chemistry, including the water cycle, in Grade10 and this prepared them for learning further concepts of water purification in Grade 11.

**Table 6: Statistics of sample schools**

Groups	Status of school	School population	Grade 11 Physical Sciences classes	Grade 11 Physical Sciences teachers	Average number of learners per class in Grade11
Experimental A	Urban boarding	1500	1	3	65
Experimental B	Day semi-urban	1700	1	4	75
Control C	Boarding rural	600	1	2	60
Control D	Day rural	900	1	2	70
Total		4700	4	11	270

### 3.2.3 Sample of the study

The learners and teachers agreed to partake the study after the researcher had explained the purpose of the investigation and convinced them that the output thereof would advance their life long knowledge and skills in research-based science and technology fields. Sampling was purposive, as contrary to random, thus teachers elected learner participants on basis of their

abilities to engage meaningfully in the project as asserted by Bogdan and Biklen (1998), and Miles and Huberman (1984). The scholar conducted the study in four high schools in Malamulele Cental Circuit, in the Vhembe district of Limpopo Province. From a total number of 270 Grade 11 learners, 32 learner participants comprising 11.9 % (16 in experimental and 16 in control groups) and four teachers from a total number of 11 teachers comprising 36.4% were selected. The sample comprised of small, purposive, non-equivalent control groups C and D and experimental groups A and B as is most common in quasi-experimental designs in educational research. In each school, teachers selected a group of eight participant learners based on their record of performance of above 60% in their Continuous Assessment (CASS) tasks (particularly in practical investigations and research projects) and in the end-of-year examination in Chemistry in Grade 10. For this group to understand further chemistry of water purification taught in Grade 11, it had first to grasp sufficiently the basic aquatic chemistry taught in Grade 10. Given large classes that were available to participate in the study, the school timetable accommodated small sample of learners (N=32), in particular control groups C and D through intact classes on the research topic [chemistry of water purification] that was concurrently running with this study. The experimental groups A and B received intervention teaching from the researcher after school hours in the afternoon and during weekends and some public holidays. The sample was purposively small not because the researcher did consider these 32 learner participants were the only who scored above 60% in grade 10 chemistry CASS, but for the following reasons:

1. The SI approach to teaching is arduous, complex and requires a lot of time to conduct learners' innovative research on the topic. In these circumstances, the official school timetable could not fully accommodate these constraints.
2. The SI instruction is expensive to run particularly with large classes, because of lack or absence of support in terms of time, laboratory chemicals and apparatus needed for such classes.
3. Another major obstacle is teachers' incompetency in SI pedagogy because of lack of training, and for large classes the researcher would have to train teachers and apply a different and appropriate research design that accommodates such classes.

The four Physical Sciences teachers, one from each school, volunteered to participate in the study. The experimental group teachers A and B had 15 and 16 years' teaching experience respectively, and they supervised the learners' projects in their schools. The control group

teachers C and D had 16 and 14 years' teaching experience respectively, and they taught and supervised learners' research projects as part of formal assessment at their schools. Before determining the control and experimental groups, the researcher with help of teachers dispensed RBT1 as pre-test and two of the schools (intact classes) were then randomly designated as experimental groups A and B and the other two as control groups C and D.

Though the scholar purposively stratified the four schools according to rural and urban proximities, they [schools] are not very far from each other. This reduced transport costs during the distribution and collection of questionnaires. These four schools were comparable in terms of geographical area as they are within a minimum 3.4 km and a maximum 12.0 km radius of each other and of the small shopping mall that is the main business centre of this peri-urban area. Schools A, B, C and D are 4.0 km, 3.4 km 3.8 km and 12.0 km respectively from the shopping mall. Schools A and B are 1.2 km apart and schools C and D are 8.2 km apart. Two other non-participating schools E and F (one rural and one urban), which were randomly chosen for pilot studies from the nearby schools were not drawn from the same population as the participating four schools, but belong to the same Circuit in Malamulele Central. The Department of Basic Education provides free transport to learners to travel to and from schools in rural areas. As access to transport is easy, the four schools have a fair mix of rural and peri-urban teachers and learners, making them comparable in terms of access to learning infrastructures.

The mean age of the learner participants was 16 years. Groups included at least two girls. Thirty-two learner participants completed the questionnaires and twenty of them participated in interview.

#### **3.2.4 Reducing possible contamination**

Learners of ease access to LAM, chemicals and apparatus formed the experimental group and any likely contact between the two groups was minimised because the intact classes used in this study were too busy with their routine lessons and studies during weekdays from 07.30 a.m. in the morning to 03.30 p.m. in the sunset. In the unlikely event, that they communicated that would not advance the control groups because the experimental groups received SI instruction (treatment) that integrated LAM, while the control groups received traditional instruction without practical activities. The two groups were also located far apart as far as

walking distance was concerned, thus reducing learners' chances of trading information on the topic.

Two teachers in the control groups offered to teach the topic during intact classes as the school schedule of the learners' research topic coincided with this study. The teachers supervised learners' research projects. The researcher taught the experimental groups and supervised their research projects.

### **3.2.5 Equal access to the programme**

After collecting the data, the researcher went back to the control groups and to the Grade 11 Physical Sciences non-participant learners and taught them chemistry of water purification through the SI approach that integrated LAM. This created equal opportunities and access to SI and helped them to acquire similar inquiry skills and knowledge of the topic as the experimental group.

## **3.3 Research instruments**

The data were collected using seven instruments: questionnaires, interviews, practical activities 1 and 2, Research-Based Tests (RBT1 and RBT2) and a Rubric Assessment Tool (RAT). According to Barret (2008), a test is a consistent and effective instrument that has the ability to evaluate the same aspect in a constant manner. Therefore, scheduled test assesses the ability that lies in apprentices as well as to produce logical deductions about their accomplishments (Elliott, Kettler, Beddow & Kurz, 2011). Practical activities 1 and 2 were included as part of the data collection instruments because of their causal effect on SI instruction as treatment using LAM.

In order to answer sub-research question 1(a), questionnaires and a semi-structured interview were developed for the learners (see Appendix 1 and Appendix 2). The questions concerned the difficult nature of chemistry and the identification of the stages of water purification and descriptions of chemical reactions occurring at each stage. In order to answer sub-research question 1(b), learners' activity sheets (see Appendix 5.1 and Appendix 7) were developed in lessons 1 and 2 respectively by the researcher. All 32 learners completed activity 1 as enrichment activity (Appendix 5.1) on the relationship of chemistry between water purification, water impurities and LAM with their teachers facilitating the process. Learners



in the experimental groups carried out practical activity 2 as extension activity (Appendix 7) as treatment only. The RBT2 addressed research question 2, and provided an answer to the effects of SI instruction compared to those of traditional instruction in this study. Teachers to all learner participants at their schools administered the RBT1 at different times on the same day.

### **3.3.1 Questionnaires on chemistry of water purification**

The questionnaire (Appendix 1) comprised nine questions in which learners' views regarding the use of LAM in teaching chemistry and parts of chemistry of water purification that are difficult to learn were investigated. In total, the respective teachers to the eight participating learners at each school distributed 32 copies of the survey. All questionnaires were returned. This response was possible because teachers handed out the questionnaires in class and learners completed them and returned them the same day. Questions 1 to 6 used Likert (1932) type items on a rating scale which was coded with numbers 0, 1, 2, 3 or 4; the questionnaire also included three open-ended questions to give learners the opportunity to reflect on their opinions.

### **3.3.2 Interviews on chemistry of water purification**

A random sample of 20 Grade 11 learners taken from the 32 participants was interviewed individually for between 20 to 30 minutes at their respective schools on different days, after school hours in the afternoon. The semi-structured interview focused on the stages of water purification, and how LAM could be used to enhance understanding of the topic. Interviews were conducted one month before implementing the teaching plan. Babbie (1993) asserts that a direct interview is flexible and relaxed and hence is appropriate when pursuing comprehensive material and ideas. The interview questions were semi-structured short and precise in order to minimise misunderstanding. The idea was to maintain consistency in the interview process. The researcher administered to the four teachers oral interviews comprising 11 questions similar to those in the learners' questionnaire and interviews. The interviews were audiotaped and transcribed verbatim by the researcher (see Appendix 2). The RBT1, RBT2 and the learners' activities 1 and 2 were constructed using the results of the interviews and questionnaires. The following information was obtained, based on the verbatim transcripts of the interviews with learners:

- the identification of the main stages of water purification, namely sand filtration, activated carbon, filtration and chlorination
- the descriptive chemistry of basic water purification steps: aeration, coagulation sedimentation, filtration, and chlorination and categorisation as either chemical or physical or biological or combined processes for removing water impurities
- the causes of water contamination: inorganic and organic impurities
- the problems experienced by learners when learning chemistry of water purification in a classroom environment
- the views of learners regarding the learning of chemistry of water purification using LAM at school.

### **3.3.3 Practical Activity 1**

The first stage of the activity 1 worksheets (Appendix 5.1) was based on lesson 1 (Appendix 5), which covered relationships in chemistry between stages of water purification, water impurities and appropriate LAM required to purify water. The class activity 1 with a total of 45 raw marks comprised six open-ended questions, mostly of the inquiry type, on physical knowledge or laboratory skills of water purification in particular. The activity was written as an enrichment task by both the control and experimental groups. Learners were allowed to consult the model diagram of water purification in Appendix 4 to help them answer the activity, particularly sections dealing with conceptual understanding of the stages and processes of water purification.

### **3.3.4 Practical Activity 2**

In activity 2, the experimental group that was taught using the SI approach undertook practical laboratory activities involving the building of a simple water purification system using LAM in order to enhance their conceptual understanding of the topic (Appendix 7). This was the crucial treatment activity that defined the experimental groups but not the control groups. The laboratory-based activity comprised 26 mostly inquiry questions with a total of 60 raw marks, focusing mainly on physical knowledge or laboratory skills, cognitive knowledge of the topic and representational knowledge in the form of chemical equations of

water purification. Inquiry type questions involving quantitative aspects or molarity of chlorination (presentational knowledge) were also included in order to improve systematic reasoning skills of the learners.

### **3.3.5 Pre-test, Research-Based Test 1 RBT1**

The RBT1 with a total of 50 raw marks was constructed using items from past examination papers related to aquatic chemistry and chemistry of water purification. The RBT1, comprising multiple-choice questions and two open-ended questions with sub-questions, was compiled (see Appendix 3). It consisted of question 1 comprising 10 multiple-choice questions, an inquiry-type question 2, which focused on concepts of water purification such as acid-base systems, equilibria, hydration and hydrolysis of ionic gases as impurities, and inquiry-based type question 3, which focused on concepts of physical, chemical and biological impurities and how LAM could be used to remove these impurities from water.

### **3.3.6 Post-test, Research-Based Test 2, RBT2**

The RBT2 related to chemistry of water purification was constructed by the researcher in order to determine learners' understanding of chemical reactions at each stage of water purification.

During the development of the RBT2, the scholar followed the following steps:

- 1) identification of instructional objectives related to the aquatic chemistry and chemistry of water purification based on the current NCS
- 2) consultation of literature related to learners' difficulties in learning chemistry of water purification
- 3) interviews with learners and completion of questionnaires in order to investigate difficult aspects of the topic which were then used to develop RBT2.

The items in RBT2, with a total of 80 raw marks, comprised question 1 made up of 10 multiple-choice items and four open-ended questions. These [questions] were developed in the light of learners' difficulties identified in the questionnaires, interviews and classroom activities 1 and 2 (see Appendices 1, 2 & 7). The questions covered all aspects of aquatic chemistry and chemistry of water purification, as discussed in Chapter 2 (see section 2.4–

2.4.4). The following concepts were probed in question 2: redox reactions and precipitations of higher oxidised metal ions in water during aeration; in question 3: acid-base systems and equilibria of chlorination of water leading to disinfection; in question 4: balancing equations of chlorination of water and chlorine as an oxidising agent and disinfectant; and, in question 5: pH dependent precipitation or coagulation of metal ions in water using alum and lime as electrolytes.

### **3.3.7 Rubric Assessment Tool (RAT)**

The RAT (Appendix 9), carrying a total of 100 marks, was adapted from the Department of Education (DoE), (2011) and University of Cape Town's (2011) Sasol School projects. It tested five major characteristics in the SI process of learners' research projects on the innovation of a water purification device at household level. This rubric was peer reviewed by the four chemistry teachers and piloted in the four schools in the learners' formal chemistry research process for Continuous Assessment (CASS). The reliability was computed at 0.85 on the (Cronbach 1970) scale.

### **3.4 Reliability of instruments**

Cronbach's Alpha was used as an indicator of the internal consistency and to illustrate the nature of the direct relationship between the aspects of each test instrument. The scholar collected data from the local schools through randomly selected teachers and learners who were not included in the sample as a pilot test and the reliability of this process was checked using Cronbach's Alpha. Cronbach's Alpha is an important indicator that measures the consistency of tools by repeatedly analysing an approximation of an assessment (Brown, 1998; Brown, 2001; Cronbach, 1970). A Cronbach Alpha estimate ( $\alpha$ ) indicates an approximation of the fraction of variance in the test scores that can be assigned to true score variance and it ranges from 0.00 (0%) to 1.00 (100%).

### **Questionnaire and interview**

The questionnaires were checked for correctness and reliability in a pilot study conducted at two nearby E and F schools. The internal consistency of the questionnaires was verified by using the split-halves reliability method (Bless & Higson-Smith, 1995). Learners' responses from each questionnaire were split into halves, the first half using the odd question numbers and the second half the even question numbers. There were now two groups of items, each

with 20 questions. The 20 learners in Grade 11 and four teachers from non-participating schools E and F used in the pilot study responded similarly to both groups of items, which ascertain the high internal consistency of the instrument. Cronbach's Alpha values for the questionnaire for learners and teachers were 0.78 (78%) and 0.85 (85%) respectively. Therefore the questionnaire was deemed reliable. The schedule for the questionnaire was similar to that of the interview, hence the interview could also be regarded as reliable.

## **RBT2**

In addition, RBT2 was piloted with 15 learners from Grade 12 in non-participating school E. An item analysis for the RBT2 indicated an alpha reliability co-efficient of 0.91(91%).

### **3.5 Validity**

After piloting the questionnaires, the aim was to ensure whether the instrument was weighing what it claimed to be weighing, and to observe if the learners' responses were well defined and relevant to the problem of teaching difficult parts of the topic using LAM as reported by Bless and Higson-Smith (1995:129–140).

### **3.6 Content validity**

Before the questionnaires and RBT1 and RBT2 were developed, a study of the literature related to the chemistry of water purification using LAM (see section 2.4), focusing on the cognitive content of the topic and SI teaching approaches was undertaken. This was done to make sure that the items were contextually correct. In order to ensure content validity of the test items the four Physical Sciences teachers not participating in the study at the two nearby schools E and F and who had taught for over 10 years revised the pre-test, RBT1 (Appendix 3), and the post-test, RBT2 (Appendix 8). They all concurred that the tests covered the chemistry content in Grade 11 adequately, particularly Learning Outcome 3 (LO3) (see section 2.3).

The researcher submitted the first draft of instruments, including the questionnaires and RBT1 & 2, to his supervisor who is professor in the Institute of Science and Technology (ISTE) at the University of South Africa (UNISA), and to other experienced chemistry teachers in the local schools for their critique. This led consequently to some reorganisation of the questionnaire and tests to certify a high cognitive standard of cogency. The content

validity of the tests and questionnaires was also confirmed with slight changes suggested by two experts in chemistry education at doctoral and professorship levels at the Institute for Science and Technology Education International Conference on Mathematics, Science and Technology (October 22–25, 2012), both of whom approved the instruments. The researcher participated in the ISTE international and national conferences twice in both cases, in 2011 and 2012. The experts checked the correspondence between items in the tests and questionnaires and identified the difficult parts of learning the chemistry of water purification. They also determined that there was one acceptable answer for each of the ten items in the multiple-choice questions in both RBT1 and RBT2 and that the five open-ended questions on chemistry identified the stages of water purification, supported by chemical equations where possible. The content validity index of the questionnaires for both the four teachers who participated in the pilot study and the 20 learners not from the sample schools was 0.80 and 0.77 respectively, whereas the content validity index of RBT1 was 0.86 and 0.75 and respectively.

### **3.7 Construct validity**

The process of developing the questionnaires began by identifying the type of information required and designing questions accordingly, in order to create the conceptual framework for preparing the pre-test and post-test. The link between the items in the questionnaire and interview schedule ensured the concept validity of water purification.

The reliability and validity of the findings were addressed by matching responses from learners on their knowledge of the chemistry and stages of water purification, through persistent observation, leaving an audit trail, checking for the representativeness of data sources and obtaining feedback from informants (Creswell, 1998; Miles & Hubermann, 1984). The study of the piloted questionnaires led to the conclusion that the instruments were within the needs of the pedagogical chemistry content knowledge level of Grade 11 learners.

#### **3.7.1 Development of activities in chemistry of Water Purification**

The activities in this study were developed by using manuals from the University of Cape Town's Department of Chemical Engineering (2011) and DWAF's (2010) South African Youth Water Prize (SAYWP), The Global Experiment of the International Year of Chemistry (IYC 2011), as well as Version 1 of the CAPS Grade 10 textbook for Physical Sciences

(Siyavula & Volunteers, 2011:309–319, 462–470). This approach was used to construct activities that would allow learners to interpret the chemistry of water purification and to construct the prototype of the water purification device at household level using LAM.

Three lesson plans prepared by the University of Cape Town (2011) on behalf of SASOL and from SAYWP and the DoE (2011) were adapted by the author, together with learners' activity sheets on the topic. The core curriculum objective of these activities was to enable learners to translate the chemistry of the topic into processes and products in the form of prototype water purification devices. This would be achieved by collecting LAM, manipulating variables and designing and developing a device through the collection of both qualitative and quantitative data.

### **3.7.2 Activity sheets (Stages of water purification, water impurities, LAM)**

The lesson objectives and the construction of the practical activity 2 are provided in Appendix 7 of the worksheet in lesson 2. The SI instruction was designed to help learners to:

- a) connect chemistry of water purification with water impurities and LAM that remove the impurities
- b) apply their new cognitive (content) knowledge when analysing chemistry of water purification with chemical equations (descriptive chemistry)
- c) choose correct LAM as well as some quantitative calculations (presentational chemistry) in the chlorination of water for the purpose of purifying water for environmental or drinking purposes at household level.

In this SI approach it was important to determine learners' knowledge of the difficult aspects of the topic before the instruction (lessons) was realised. The worksheet for practical activity 2 (see Appendix 7) consists of three sections:

- a) learners' difficulties identified from interviews, questionnaires and RBT1
- b) the practical activity (building a simple water purification system using LAM) and
- c) questions on chemistry of water purification and correct use of LAM to remove impurities.

### **3.7.3 Administration of instruments**

The activities developed in lesson 1 (Appendix 5.1) were implemented as practical-based or enrichment activities in double lessons (2 x 45 minutes) during intact afternoon studies for both experimental and control groups on different days. Activity 2 for the experimental group was a practical lesson (see Appendix 7) that focused on the building of a simple water purification system using LAM in the classroom. The control group did not carry out practical activity 2 (control strategy) as they were engaged in intact-class discussions and problem solving in activity 1 with their teachers. After administering questionnaires and interviews, the pre-test RBT1 was administered to the 32 learners by their teachers at their respective schools. The post-test, RBT2, was administered at the end of the activities in lesson 3 prior to the construction of the water purification devices by the learners. Learners completed the test in a 50 minute period. The answer sheets were collected, marked and analysed by the researcher.

### **3.8 Procedure: Intervention (Scientific Inquiry instruction)**

This section discusses the grouping and stages of implementation in the research design in addressing the crucial aspect of this study, the actual teaching of the chemistry of water purification integrating LAM through an SI approach. The first stage of the worksheet in activity 2 (see Appendix 7) focused on the difficult aspects of the five steps in basic chemistry of water purification, as reported in the analysis of interviews and questionnaires: aeration, coagulation, sedimentation, filtration, and disinfection of water using chlorine.

The two groups spent equal periods studying the chemistry of water purification and completing an innovative research task comprising the building of water purification devices (see Appendix 6). The major difference between the two groups was that the experimental group carried out the practical activity in lesson 2 while the control group did not. The intervention involved six contact teaching hours over three weeks. Teachers supervised learners' research projects for four months in both groups, as participants were working with household and laboratory chemicals in the laboratory as part of their investigation. Both experimental and control groups wrote the RBT1 and 2, completed activity 1 and the RAT. However, the experimental groups completed activity 2 that was treatment only. The time allocated to the teaching and facilitating of research topics such as water purification in NCS is usually 11 weeks (one school term), while in the new CAPS, 22 weeks are allowed. The



first lesson in the study was on basic aquatic chemistry and chemistry concepts of water purification, in order for the learners to develop the conceptual framework concerning the chemical processes of the topic. Learners completed activity sheets in lesson 2 (see Appendix 7) as they carried out these activities.

In the first lesson, a double lesson (Appendix 5), learners were given a model diagram of water purification (application chemistry of water purification) (see Appendix 4), and they were asked to identify and draw mind maps of a proposed water purification device using LAM, and to describe the purification processes occurring at each stage with the aid of chemical equations. In lesson 2, a double lesson, the researcher introduced learners to the SI method through pre-laboratory and pre-research lessons.

The post-test (RBT2) was dispensed to both the experimental and control groups immediately after trials with activities in lesson 3 (see Appendix 9). After four months the prototype of the water purification device was completed. The completed activity sheets and RAT were marked to quantify the significance of this SI approach. The raw marks were expressed as percentages for RAT (see Table 24 and Appendix 7).

### **Experimental group A and B:**

In experimental groups A and B, where Scientific Inquiry (SI) was utilised, learners were first informed about this innovative instruction and its processes. In these groups, the learners went through five successive stages of inquiry as described here, while those in the control groups did not. The researcher using lessons 1, 2 and 3 taught the experimental groups. These groups were supervised and received additional SI instruction from the researcher for four months using inquiry activities in the building of water purification systems using LAM and in the learners' innovation project (see Appendix 6), as described in lesson 2. The lessons in activity 2 focused mainly on prepared worksheets and demonstrations of a simple water purification system. The experimental groups devoted additional time to doing research work guided by researcher as opposed to the control groups that spent more time with teachers doing in-class discussion of the topic during intact classes. In the practical activity of designing a water purification system learners used LAM with which they were familiar, such as sand, silt, gravel, crushed glass particles for filtration, charred vegetation and charred bones for adsorption of chemical impurities and bleach for chlorination to kill pathogens. At

the end of the demonstration, discussions guided by the researcher encouraged learners to identify and explain with chemical equations the difficult aspects of the chemistry of water purification from the outcome of the demonstration.

### **Control group C and D:**

Learners in the control groups were not informed about SI as a new teaching and learning approach to the topic. Their respective teachers through the traditional approach using intact classes taught these groups. This study coincided with learners' formal research projects for CASS. The teachers used a teacher-centred approach. The usual chalkboard approach that included in-class discussions and problem solving without worksheets, and practical sessions dominated this approach. The outcome of learners' research was realisation of a simple water purification system that was built using LAM. The topic was taught through theoretical and practical explanations of the chemistry of water purification and presented in an innovative research project task, which was handed to the learners during the first lesson as an activity extension.

### **The lessons (see Appendices 5, 7 and 8)**

The learners went through five successive stages in the experimental groups.

**In Stage 1**, lesson 1 was completed in two days, with each day allocated 90 minutes, the equivalent of a double lesson. The first session covered the theory of the chemistry of water purification and the second session, an enrichment activity to RBT1, covered the relationship in chemistry between stages of purification, water impurities and LAM (Appendix 5). Teaching of Water Purification in lesson 1 was supported with a model diagram of household water purification (Appendix 4) that illustrated the stages of water purification, and was guided by in-class discussions using examples of LAM that could be used to decontaminate water. The learners were presented with an innovative research project task (Appendix 6) as an activity extension at the end of lesson 1, which they studied cautiously. They were urged to write down their perspectives about the research project on the "need to know" worksheets. The learners were informed that their research project would be of an innovative type with a time line of four months. Learners had to identify and describe the problem of the looming shortage of fresh water resources and to create opportunities to demonstrate that they were able to address the problem by applying the chemistry of water purification. The

researcher encouraged learners to derive the title from the intended focus of the study, i.e. the chemistry of water purification using LAM. Therefore learners were expected to coin a creative title such as *How to apply chemistry of water purification in the construction of a water purification device using LAM*.

Both the experimental and control groups completed extension activity 1 (Appendix 5.1). The researcher marked and compared the performance of the two groups in this activity and in pre-test (RBT1), as reported in Chapter 4, sub section 4.3.1.

**In Stage 2**, in lesson 2, the learners identified the parts of the chemistry of that they found difficult and organised them around three focus questions as suggested by Gallagher et al. 1995 using a “need-to-know” worksheet. The learners recorded their ideas and questions on this worksheet regularly as a group. In this way, the worksheets served as “a central focus point for the unit and represented the continuing cycle of problem definition, information gathering, analysis and synthesis of information, and problem redefinition” (Gallagher et al. 1995:141). In Gallagher et al. (1995), in an enquiry-problem based lesson, the teacher is instructed to start out with a strategy of questioning how learners think about chemistry of water purification at school and to list their reasons for thinking that the topic is important at home in their “need to know” worksheets. In this study, learners were given the opportunity to discuss ways in which chemistry of water purification can render itself into the simple technology of water purification at household level. The researcher's use of questioning invokes Vygotsky's notion of mediated learning in the zone of proximal development (ZPD) as learners appropriated knowledge and skills through this interaction during the stages of investigation through the “need to know” worksheet. When formulating their own questions, the researcher supported learners by ensuring that the questions they posed were clear and investigable. Support in this initial phase is particularly important and identifying a question plays a critical role because it gives meaning and direction to what follows (Howes, Lim & Campos, 2009; Kuhn, 2007). Some of the “productive” types of questions asked by the researcher of learners at the initial stages of their investigation are stated below:

1. What do you know about the chemistry of water purification? Write your ideas and questions about the chemistry of water purification using LAM on the “need-to-know” worksheet.

2. How can you find out what you want to know about water purification using locally available materials?
3. Design a prototype of a water purification device using a schematic diagram with appropriate locally available materials.

This strategy of teaching the topic through SI using LAM was guided by the constructivist theory as learners constructed knowledge in their application of the chemistry of water purification when building a simple water purification system in the classroom and developing a prototype of a water purification device as part of their research project.

**In Stage 3**, the learners acquired further knowledge and higher conceptual understanding of the chemistry of the topic from lesson 1, in order to answer their own questions through SI. Learners used the science laboratory to carry out their investigations in lesson 2 and some looked up information in print and electronic resources using both the library and the internet, while still others consulted expert professionals.

The practical Activity 2 that required learners to build a simple water purification system in the laboratory using LAM, designed to apply chemistry of water purification and in particular to demonstrate the chemical reactions occurring at each stage of the process, was not “new” but was adapted, with slight modifications, from *Laboratory Module 6. Hands on activities: Water experiments* (The International Year of Chemistry, IYC, 2011). The adaptations concerned chiefly the chlorination of filtered water by bleach powder. The researcher’s adapted class module included the process of chlorination that was not included in the ICY’s (2011) Laboratory Module 6. The goals of lesson 2, laboratory Activity 2, were: to develop skills for handling and analysing data, to teach proper laboratory techniques, and to reinforce concepts of chemistry related to water purification that had been taught in lesson 1 and in grade 10.

In order to demonstrate the stages of Water Purification using LAM in the classroom by building a simple water purification system, the researcher needed the LAM and chemicals as detailed in Literature Review (sub section 2.5.1: Improvisation in teaching water purification), lesson 1 (Appendix 7: Building a simple water purification system using LAM ) and Figure 4.

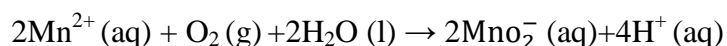
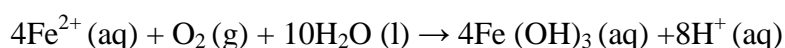


**Figure 4: Prototype of water purification system developed using locally available materials<sup>8</sup>**

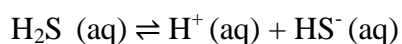
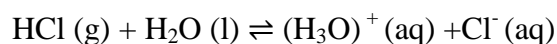
During class discussions, the researcher explained the chemical reactions that occur at each stage of water purification using these LAM, as described in lesson 2 (see Appendix 7). This formed the project focus or literature review for the learners' innovation project of making prototypes of water purification devices at household level using LAM.

The chemistry of the five steps of simple water purification comprise: aeration, coagulation, sedimentation, filtration, and disinfection.

- a) Aeration allows gases trapped in the water to escape and adds oxygen to the water. Metal contaminants such as  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$  ions are oxidised into higher oxidation states of +3 and +7 which precipitate out of grey water:



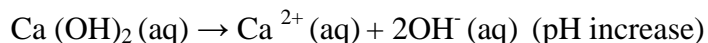
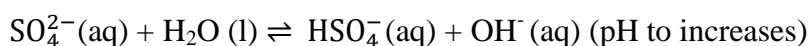
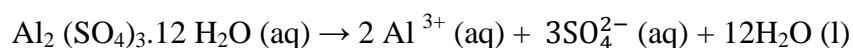
Hydrogen sulphide, ammonia, and volatile organic compounds escape from water as impure gases. A gas or ionic substance dissolved in water may further react with water through hydration:



<sup>8</sup>Source: [<http://www.hometrainingtools.com/a/water-filtration-science-project/>]

These reactions are reversible, and aeration may cause dehydration, resulting in the release of the impure gases from water.

- b) Coagulation, flocculation and sedimentation are processes used in the pre-treatment of wastewater. The addition of electrolytes such as aluminium sulphate ( $\text{Al}_2(\text{SO}_4)_3 \cdot 12\text{H}_2\text{O}$ ) and lime ( $\text{Ca}(\text{OH})_2$ ) causes coagulation as colloids are neutralised when they chemically combine with ions in water, forming larger particles called flocs (clumps of alum and sediment), which settle down on the bottom of the container. Flocs entrap waste particles in water. This process clarifies dirty and muddy water.
- c) Sedimentation or settling using silt occurs when gravity pulls the particles of floc to the bottom of the container. Alum, lime and other electrolytes cause the pH of water to increase or become basic as a result of the following reactions:



In this basic aqueous solution, aluminium hydroxide,  $\text{Al}(\text{OH})_3$ , iron hydroxide,  $\text{Fe}(\text{OH})_3$  and iron (II) hydroxide,  $\text{Fe}(\text{OH})_2$  precipitate out the small particulates of dirty and mud in water, and the water becomes clear. Coagulation and flocculation can also remove impurities such as suspensions of iron oxide and organic matter that give water a muddy yellow appearance.

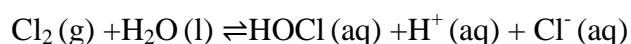
- d) Sand filtration is the process through which remaining solid particles and floc are removed from the water. As water percolates, the sand filter media organic matter breaks down and particles stick to sand surfaces or are trapped in sand spaces. Negatively charged sand surface grains/particles attract positively charged waste materials and bond by adsorption.

Some waste particles are also removed by chemical bonding with the sand filter media. After about two weeks, the sand filter matures and develops a filter ecosystem, a thick surface layer called biomat, rich in bacteria that consume the organic waste particles. Protozoa in turn feed

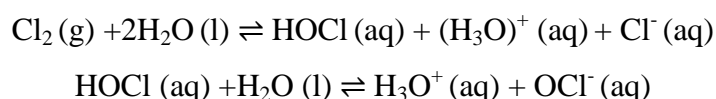
on bacteria and prevent the biomat from clogging the sand filter. This food chain in the filter ecosystem together with physico-chemical processes turns water colourless and odourless.

- e) Disinfection is the final step, in which water is chemically treated with chlorine bleach to remove bacteria and other micro-organisms, making it suitable for drinking. Chlorine kills pathogens such as bacteria and viruses by breaking the chemical bonds in their molecular cell walls. This results in one or more of the hydrogen atoms in the bacterial enzyme molecule or cell is replaced by chlorine, the entire molecule changes shape, leading to death.

When chlorine is added to water hypochlorous a weak acid forms:



Depending on the pH value, hypochlorous acid partially dissociates to hypochlorite ions:



This dissociates to chlorine and oxygen atoms:



Hypochlorous acid (HOCl, which is electrically neutral) and hypochlorite ions (OCl<sup>-</sup>, electrically negative) will form free chlorine when bound together. This results in disinfection. Hypochlorous acid is more reactive and is a stronger disinfectant than hypochlorite ions. Hypochlorous acid is split into hydrochloric acid (HCl) and oxygen atom (O) that is also a powerful disinfectant.

The cell wall of pathogens that are negatively charged can be penetrated by the neutral hypochlorous acid, rather than by the negatively charged hypochlorite ion. Hypochlorous acid can penetrate slime layers, cell walls and protective layers of microorganisms and kill them.

**In Stage 4**, after trials in lesson 3 with activities in lessons 1 and 2 on the synthesis and analysis (application) of the chemistry of water purification, RBT2 was administered as a post-test to both the experimental and the control groups.

**In Stage 5**, the learners in both the experimental and the control groups presented a report on their progress in making the prototype of a water purification device to the class. Each group gave a 5–10 minute oral presentation on what they had learned through their innovation. The learners also submitted a group report that documented the group's findings and provided details of the inquiry process. The researcher evaluated the groups using the RAT (Appendix 9), based on criteria related to both the process and the product of the teaching of the chemistry of water purification using LAM.

### **3.9 Ethical considerations**

The circuit manager of Malamulele Central Circuit in the Vhembe District acted as a representative of the DoE in response to the scholar's request to carry out research in schools (Appendices 10 and 11). The principals also gave written consent to conduct the study at their schools. The Department advised that the contact with learners and teachers should not disturb teaching and learning programmes in schools. Participating teachers gave consent by signing a participant consent declaration (Appendix 13) and as for the learners, consent was granted by their parents or guardians, who signed the parent/guardian agreement form to allow the participation of their child in the research study (Appendix 12).

The project proposal was also endorsed by the ethics committee of the university (Appendix 14). The University of South Africa (UNISA) and the researcher funded this project. Both teacher and learner participants were enlightened that their participation would be voluntary and that they could withdraw at any time. However, no participant withdrew. Teachers and learners were assured that anonymity would be preserved.



## CHAPTER 4: DATA PRESENTATION, RESULTS AND DISCUSSION

### 4.1 Précis

The data were collected in three stages in order to answer the main research question: *What are the features of an effective approach to teaching water purification to Grade 11 learners using locally available materials (LAM)?*

Stage1: In order to establish the conceptual framework and answer sub-question (1a): *Which parts of the chemistry of water purification present Grade 11 learners with difficulties?*

Difficulties in learning chemistry of water purification were identified in the literature and from the analysis of the questionnaires and interviews with Grade 11 learners. The data collected focused mainly on learners' views, knowledge and understanding of the chemistry of water purification.

Stage 2: Practical Activity 2 (Appendix 7), which used LAM in the building of a simple water purification system in the classroom, was completed by the experimental groups, addressing sub-question (1b): *How can locally available materials (LAM) be incorporated into Grade 11 Chemistry instruction to enhance learners' understanding of the stages of water purification?*

Stage 3: After the trial of the activities the written tests, pre-test RBT1 and post-test RBT2, were analysed using *t*-tests independently in order to address research question 2 on the effects of SI instruction.

### 4.2 Findings of the study

#### 4.2.1 Sub research question 1(a): Results from the questionnaire for learners

Stage 1: *Which parts of the chemistry of water purification present Grade 11 learners with difficulties?*

1. Performance in Paper 2 (Chemistry) examination in Grade 10:

**Table 7: Performance in chemistry**

Performance Score	Number of learners	%
Fail: Below 30%	1	3.1
Pass: 31–79%	29	90.6
Above: 80%	2	6.3

2. Performance in research project of Paper 2 (Chemistry) in Grade 10:

**Table 8: Performance in chemistry research**

Performance Score	Number of learners	%
Fail: Below 30%	1	3.1
Pass: 30% and above	31	96.9

Tables 7 and 8 show that of the 32 learners who completed the questionnaires, 31 (96.9%) passed chemistry promotion examination and chemistry research projects in Grade 10.

3. Physical knowledge, experience or skills in the chemistry laboratory

**Table 9: Laboratory experience or skills**

Rating	Number of learners	%
Poor	24	75.0
Fair	6	18.8
Satisfactory	2	6.2
Good	0	0.0
Very good	0	0.0

In the study sample of 32 learners, 24 (75.0%) and six (18.8%) were rated “poor” and “fair”, respectively, regarding their prior physical knowledge or skills required to actually perform the laboratory tasks involved in scientific inquiry. Only two learners, representing 6.2%, understood the procedure of inquiry (Table 9).

4. What do you consider important when learning the chemistry of water purification?

**Table 10: Effective learning approach**

Learning approach	Number of learners	%
Notes on concepts	5	15.6
Tests	7	21.9
Practical activities	20	62.5

From the information in Table 10, it is clear that the majority of learners (20, or 62.5%) preferred carrying out practical activities when learning the chemistry of water purification.

5. Knowledge of the stages of water purification

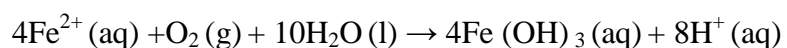
**Table 11: Knowledge of water purification**

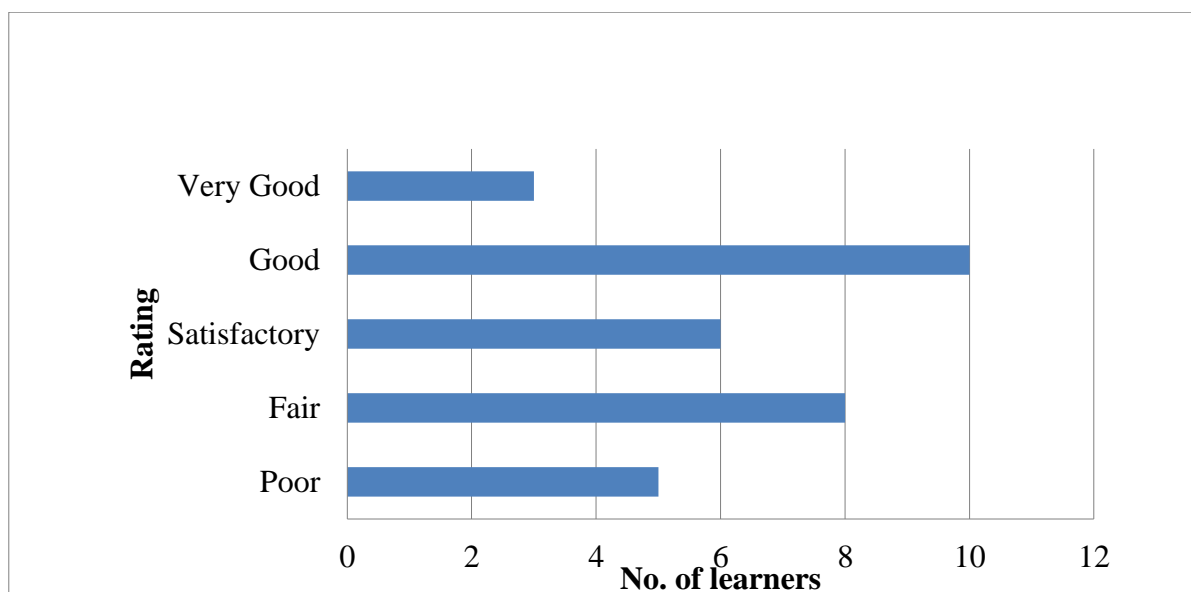
Rating	Number of learners	%
Poor	2	6.3
Fair	1	3.1
Satisfactory	7	21.8
Good	11	34.4
Very good	11	34.4

Table 11 shows that a minority of two learners (6.3%) did not acquire any knowledge about the chemistry of water purification in Grade 10.

6.0 Learners were asked to evaluate their knowledge of the chemical reactions represented by chemical equations (6.1–6.1.2) that occur at different stages in the chemistry of water purification.

6.1 *Aeration* through sand filtration precipitates metal ions as impurities in water:

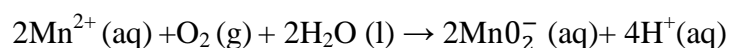




**Figure 5: Understanding of precipitation of  $\text{Fe}^{3+}$  in water**

In question 6.1, only five (15.6%) learners had difficulties with the redox system and precipitation of  $\text{Fe}^{2+}$  ions into a higher oxidation state of +3 as contaminant in water during aeration. In Figure 5 a significant percentage of learners rated their understanding of the formula as fair or satisfactory (25.0 % and 18.6% respectively). A similar trend was observed in Table 12 in the case of precipitation of manganese ions into a higher oxidation state of +7, with only 9.4% of learners having difficulties in understanding the precipitation and redox reactions, and a significant number of learners, nine (28.1%) and four (12.5%), rated their understanding of the formula as fair and satisfactory respectively.

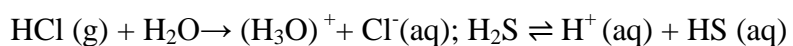
#### 6.1.1



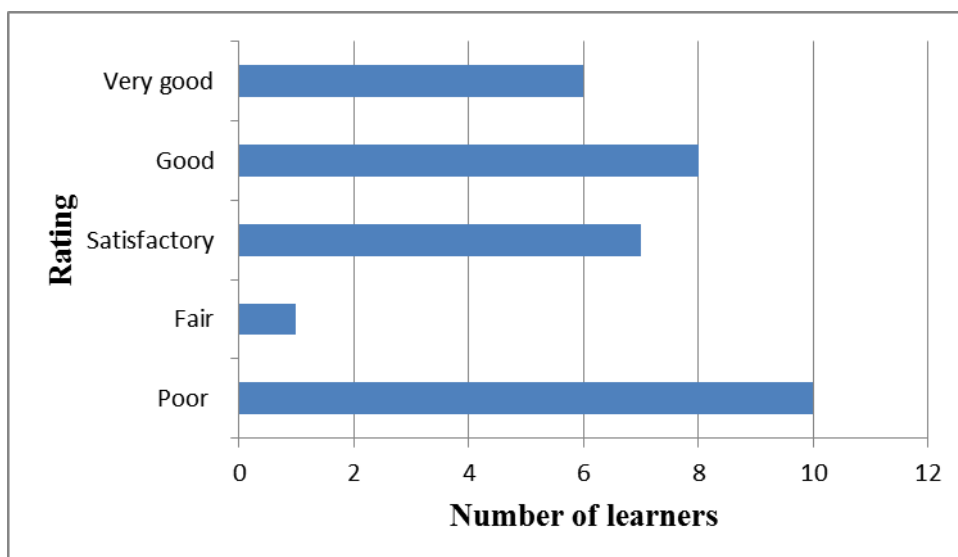
**Table 12: Understanding of precipitation of +7 manganese ions**

Rating	Number of learners	%
Poor	3	9.4
Fair	9	28.1
Satisfactory	4	12.5
Good	9	28.1
Very good	7	21.9

6.1.2 Trapping of gas in water:



The results shown in Figure 6 reveal that a significant 31.3% of the 32 learners had serious difficulties in understanding hydration and hydrolysis in solution chemistry.



**Figure 6: Understanding of hydration and hydrolysis of H<sub>2</sub>S water**

6.2 *Coagulation* by addition of alum and lime (electrolytes) causes the pH of the water to increase and the precipitation of small particles as impurities in water:

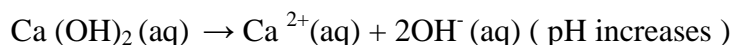
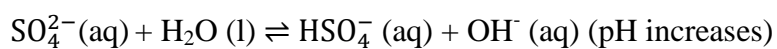
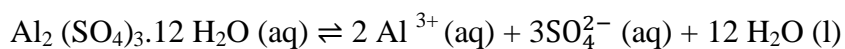
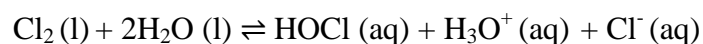


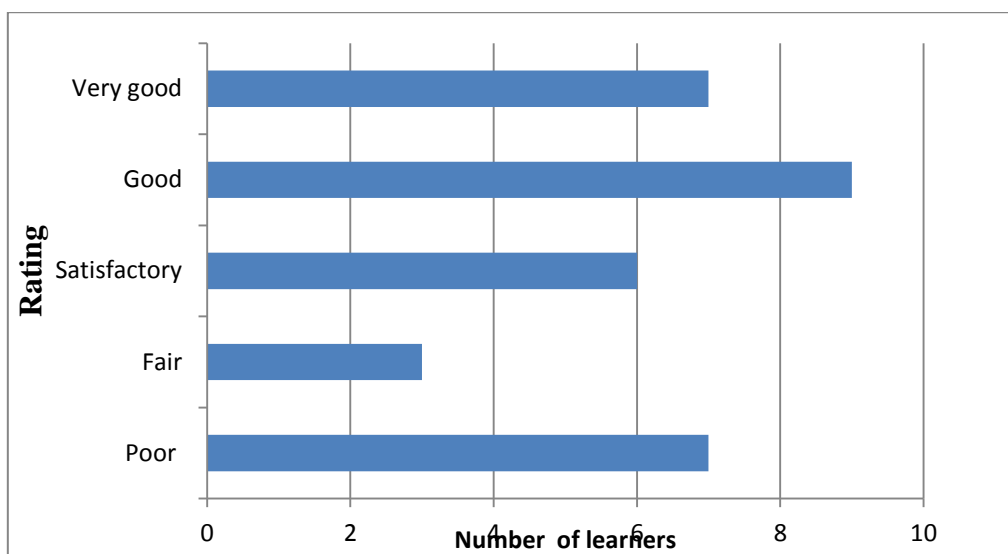
Table 13 shows that electrochemistry that involves solution chemistry of acid and base dependent equilibrium and precipitations of ions such as  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  in water during coagulation was not well understood, with 15.6%, 3.1% and 28.1% of the 32 learners being rated poor, fair and satisfactory respectively.

**Table 13: Understanding of the precipitation of  $\text{Al}^{3+}$  ions in water**

Rating	Number of learners	%
Poor	5	15.6
Fair	1	3.1
Satisfactory	9	28.1
Good	9	28.1
Very good	8	25.1

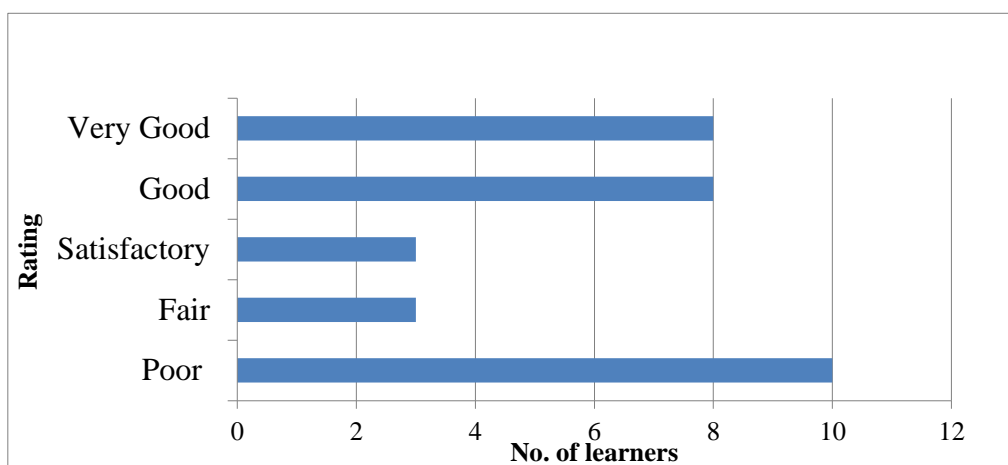
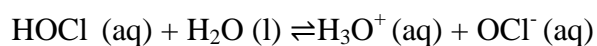
6.3 Chlorination:





**Figure 7: Understanding of the hydrolysis of chlorine in water**

6.4

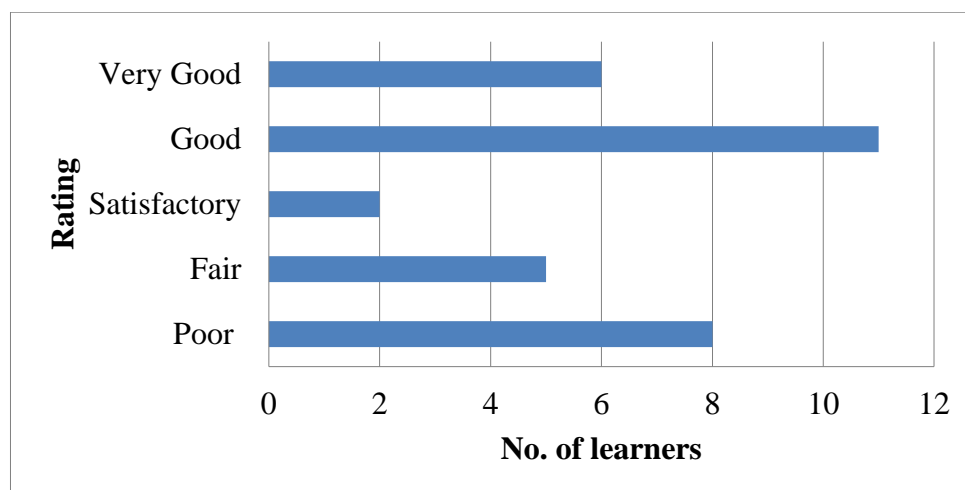


**Figure 8: Understanding of the partial dissociation of hypochlorous acid in water**

6.5







**Figure 9: Understanding of the dissociation of hypochlorite ions in water**

An analysis of the understanding of the chemistry of chlorine in water by learners in general shows that a significant number had trouble in learning the acid-base system and equilibria concepts of chlorination. Figures 7, 8 and 9 show that 21.9%, 31.3% and 25.0%, respectively, of learners had problems in learning the chemistry of chlorination, particularly in understanding chemical and ionic dissociation equations and formulae. In the literature there have been a number of studies that have addressed these problem areas of learning concepts of acids and bases.

Responses to inquiry question 7 indicate that 75.0% of learners suggested that research topics such as chemistry of water purification should be taught and learnt through activities such as practical investigations, experiments and educational tours to municipal water purification plants. Traditional approaches to teaching and learning practical based tasks generated a relatively low positive response rate of 12.5%. In inquiry question 8, the order of difficulty of learning chemistry of water purification indicated that 56.3% of learners experienced difficulties in balancing chemical equations and formulae, a significant 28.1% had no knowledge of the chemical equations, and 12.5% reported that they did not understand coagulation or precipitation, although only 3.1% had problems with the chemistry of chlorination. In conclusion, responses to question 9 show that a total of 81.2% of learners noted that chemical equations of water purification are highly conceptual and abstract, pointing to the need for both a theoretical and a practical approach to learning and teaching if meaningful understanding is to take place in the classroom.

#### **4.2.2 Sub Research question 1(a): Results from interviews with learners**

Interviews elicited the learners' views and their difficulties in learning the chemistry of water purification, and were transcribed verbatim. The findings from the first five questions, the responses to which were coded as positive (0) or negative (1) are discussed here (see Appendix 2).

More than half the learners interviewed responded positively regarding their knowledge and understanding of the chemistry of water purification, the causes of water contamination and the availability and use of household chemicals such as bleach to disinfect water at household level. However, the description of water purification provided by most learners lacked the basic concepts of aquatic and descriptive chemistry as general terms such as “Cleaning of dirty water, removal of germs, rubbish, dirty, chemical, organic matter and human activities” were often used to characterise the contaminants of water. Few learners were able to categorise or differentiate impurities into physical, chemical (organic and inorganic) and biological types. This finding is supported by the observations of Osborne and Cosgrove (1983) who proved how students of various age groups did not sufficiently grasp the microscopic thought of chemistry or chemical events in their routine lives.

A response for each type of inquiry question from questions six to 11 was coded with numbers 0,1,2,3 or 4 (see Appendix 2). Question six probed learners' understanding of the physico-chemistry of sand filtration, active carbon adsorption and coagulation or precipitations. More than half the learners responded positively, indicating that they had understood the basic chemistry underpinning these concepts. Chlorination was problematic, with 60% providing negative responses, reflecting the results from the questionnaires as depicted in Figures 7, 8 and 9, suggesting that balancing chemical equations, acid-base systems, pH and chemical and ionic equilibrium systems proved difficult for learners.

Question seven asked learners to provide constructive feedback on how best they could learn the chemistry of water purification in the classroom in order to enhance their understanding of concepts. Learners' responses indicated that practical tasks such as research projects, experiments and chemistry based educational tours would be the most popular approaches to the pedagogy of the chemistry of water purification, again related in the analysis of questions seven and nine of the questionnaire (see Appendix 1). A significant 60% of the learners felt

that the change from traditional classroom lessons dominated by chalkboard practice to inquiry-based lessons comprising a theory-practice-application approach was more intrinsically motivating, since most learners mastered the chemistry concepts they had acquired in the classroom lessons.

Question eight probed learners' perceptions of the difficult nature of chemistry, with 70% responding positively that they did not find basic chemistry of water purification difficult to understand, provided it was taught and learnt from a practical approach. As the topic was familiar to learners from an environmental point of view it generated interest and motivation. Learners further suggested that teachers should use innovative teaching approaches to teach research topics by manipulating LAM and resources, particularly when infrastructure for practical activities at school was inadequate or completely lacking.

Question nine required learners to comment on their performance in chemistry in Grade 10; 80% responded positively, saying that they had passed their promotion chemistry examination, as noted in positive responses to questions one and two of the questionnaire (see Appendix 1). Although none of the learners felt that practical tasks had directly influenced their promotion to Grade 11, they acknowledged that it was the relationship between theory and practice that was critical to a real understanding of chemistry.

Question ten investigated the problems that learners experience when learning the chemistry of water purification in the classroom. Almost a third (30%) responded negatively, indicating that they did not understand, while 60% did not understand the topic sufficiently since their background knowledge was inadequate for a number of reasons, amongst them teachers' incompetence, a lack of apparatus and chemicals, irrelevant textbooks that did not relate theory to practice, and traditional approaches to teaching. This negative response was similar to that observed in the responses to question eight of the questionnaire that indicated that the processes of water purification such as chlorination of water need to be taught and learnt meaningfully through practical approaches. Question eleven probed learners' feelings about the interview on the chemistry of water purification, with 80% responding positively that their interest and motivation in learning chemistry had been elevated since this was the first time that they had been given the opportunity to actively participate in such a study that pursued their views on how best chemistry could be learnt and taught in schools.

### **4.2.3 Sub research question 1(b): Locally Available Materials**

This sub section gives detailed findings on the use of LAM in addressing appropriateness of LAM through the learners' engagement in practical activities on water purification, and their conceptual understanding of the chemistry that links LAM and water impurities. In this respect, the following sub research question focuses on improvisation of LAM to improve learners' autonomy and intrinsic motivation hence understanding of topic.

**Stage 2:** *How can LAM be incorporated into Grade 11 Chemistry instruction to enhance learners' understanding of the stages of water purification?*

### **4.2.4 Sub research question 1(b): Building a simple water purification system using LAM**

In a class discussions during a pre-laboratory session, the learners suggested that LAM such as sand, silt and gravel, crushed glass filings, mineral particles and bottom ash could be used for aeration and filtration of solid impurities in water, and that solid bleach calcium hypochlorite or liquid bleach sodium hypochlorite could be used to kill pathogens. In practical activity 2 in lesson 2 the researcher effectively taught the difficult aspects of the chemistry of water purification using the SI approach that incorporated LAM in order to enhance learners' understanding of the chemistry occurring at the various stages of water purification

Learners filled in activity sheets that contained clear instructions on how to build a simple water purification system using LAM. The questions required learners to forecast, monitor and describe the basic chemistry of water purification and to draw a diagram illustrating the five simple phases of the water purification process using LAM. The learners collected apparatus, LAM, and chemicals, following the instructions in the scientific procedure that was provided for the building of a water purification system in the classroom discussed in Appendix 7 and Procedure in sub section 3.8.

Fourteen of the 16 items needed to carry out the practical activity were LAM. The alum and litmus indicator or universal indicators were the only processed materials (chemicals) that were not readily available; therefore the researcher had to procure it so that learners could complete the activity. The learners completed the practical activity and drew the diagram of the Water Purification System on the board, showing how LAM were used at each stage of

water purification. Then one learner asked other learners to describe what happened at each stage of water purification. One learner explained this (see Figure 4 & section 3.8), as taught by the researcher in the procedure.

Physical filtration to remove solid particles such as stones, muddy clay, small organisms such as worms etc. is achieved by a layer of fine sand, coarse sand and small stones, in that order, from top to bottom of filter bottle container. Air that moves through airspaces of packed soil particles comprise oxygen that is needed for respiration of microbes in muddy water, particularly bacteria. A lot of air in water also allows contaminant gases such as hydrogen sulphide in water to escape in a reversible reaction to hydration and hydrolysis of these gases. Addition of alum in grey water/muddy water combines solid impurities into a mass of aggregates (plods) by attaching to each other. This process is called coagulation. This makes water clean and colourless. The force of gravity makes process of sedimentation (settling) easy because the aggregates (plods) are pulled down to the bottom of the filter bottle bed. Sand filtration removes residues of solid particles and plods from water. In disinfection stage, bleach that contains chlorine, and we use at home as a disinfectant kills the pathogens such as bacteria and fungi that cause diseases.

#### **4.2.5 Sub research question 1(b): LAM used in water purification devices**

Both the experimental and the control group learners made their water purification devices using LAM, following the SI method (Appendix 6). Findings on how LAM were used by learners to enhance their understanding of the stages of water purification are illustrated by pictures of the prototypes of water purification devices at household level (see Figures 13, 14, 15 and 16). Learners used the SI method to conduct their innovative research project, using LAM to make these devices. Group project write-ups and the present prototypes constituted the findings on how LAM were used by learners to enhance their learning of the stages of water purification. LAM such as sand, silt, gravel, crushed glass filings for filtration, charred vegetation or charred bones for adsorption of chemical impurities and bleach for chlorination, killing pathogens in water, were used by the learners in their innovative research projects. The focus here was on the correct choice of LAM in the design and technology of the device.

#### **Experimental group A**

Research design and methodology (61%)

The device (see Figure 13) includes three plastic bottle chambers (upper, middle and lower) connected by hard polyvinylchloride (PVC) pipes that are held in position by a wire frame.

Learners were able to formulate good and clear research questions that specified the LAM to be used in the design and construction of the water purification device.

The device was assembled from LAM using three 2-litre plastic bottles connected with pipes. The device is held in position by a wire frame. The three chambers represent different stages in the filtration process. The first chamber is a sand filter chamber that removes insects, small organisms and some solids. The second chamber is a charred vegetation filter for removing chemical impurities. The third chamber is used to chlorinate the water to deactivate pathogens. The device is constructed of inexpensive LAM and serves its simple purpose of purifying grey water.

#### **Experimental group B**      Research design and methodology (78%)

The design consists of three plastic bottle chambers assembled from LAM that represent the three filtration processes, namely a sand filter for removing solids, a charcoal filter for removing chemical impurities by adsorption, and a chlorination chamber to kill pathogens ( see Figure 14).

The variables for the device procedure were correctly identified as time (independent), LAM, chemistry knowledge of water purification and skills (dependent) and volume and area measurements (controlled). Using the available literature, the learners identified three stages of water purification in line with the availability of LAM, namely a sand filter, a carbon filter and chlorination. In the production of the device, learners first drew a linear flowchart describing the design of the device and illustrating the three major purification stages linked by flow arrows from the top to the bottom chambers, so that water could flow down the system by the force of gravity. Learners explained, where possible using chemical equations, the processes occurring in sand filtration as the physical separation of removing solids from water, in carbon filtration as chemical adsorption of metal ions in water and in chlorination by bleach as the biological destruction of pathogenic organisms.

#### **Control group C**      Research design and methodology (64%)

The approach was a narrative, as opposed to the making of the device using LAM. The materials collected (paper, stroke pipes and sand) were suitable for constructing the design model, but not the actual device. The description of the embodiment of the device in the form

of a design using LAM is shown in Figure 15 and comprises three chambers with a sand filter, a carbon filter and a chlorination chamber.

#### **Control group D**      Research design and methodology (32%)

The water purification device was constructed using three chambers in a vertical arrangement, representing the three stages of purification of grey water, namely a sand and stone filter with a plastic bottle for removing solids on top, a plastic bottle filled with charred vegetation for removing chemical impurities, and a plastic bottle containing bleach for killing pathogens.

The chemistry processes of water purification, namely a sand filter, a charcoal filter and chlorination, were identified as the main stages in the realisation of the device. The device in Figure 16 was constructed without a design plan or drawing. However, marks were awarded for the use of LAM to make the device. The device consists of three 2-litre plastic bottles in a vertical arrangement connected by plastic straws. Although the learners assembled the device according to the model diagram provided (see Figure 4: model diagram of water purification (recycling) at household level), they failed to explain the physico-chemical processes that occurred at each stage, namely the sand and stones in the top chamber filtering solids, the middle chamber containing charcoal for the removal of chemical impurities, and the bottom chamber for chlorination.

### **4.3 Statistical Analysis of Data**

Stage 3: *Is there any difference in the performance of learners taught water purification processes using locally available materials (LAM) by Scientific Inquiry (SI) approach and those taught using the traditional teaching approach?*

#### **4.3.1 Analysis of marked activity sheets**

**Table 14: Summary of the raw scores in percentages in set activities and written tests for experimental and control groups.**

Learner/group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Experimental /RBT2	75	85	95	90	96	78	88	92	60	80	70	75	70	73	89	78
Experimental /Activity 1	48	66	53	74	58	88	59	78	66	50	70	58	78	57	88	59
Experimental /Activity 2	78	66	88	90	94	82	70	86	66	58	60	78	84	96	90	84
Control. /RBT2	65	55	70	55	65	63	58	60	65	66	67	65	63	52	60	58
Control /Activity 1	10	18	28	32	34	33	36	48	16	20	30	36	38	40	50	68

The completed activity sheets were marked to quantify the effectiveness of this inquiry based instruction. Table 14 shows the scores as percentages for learners' activities 1 (Appendix 5.1) and 2 (Appendix 7) and post-test (RBT2) that were analysed by descriptive statistics and validated by the *t*-test for learners in the experimental groups A and B and the control groups C and D. The first stage of learners' activity 1 the worksheets, was based on lesson 1, which covered relationships in chemistry between stages of water purification, water impurities and appropriate LAM required to purify water. In learners' activity 2, the experimental group, taught by the SI approach, undertook practical activities on the building of a simple water purification system using LAM in order to enhance their conceptual understanding of the topic (Appendix 7). The analysis of the data revealed that there were significant differences in mean performance in activity 1 between the two groups, in favour of the experimental group, as reflected below in Table 15.



**Table 15: Post response activity 1 of experimental groups A and B and control groups C and D. (Independent t-test results)**

Parameter	Experimental group	Control group
Mean ( $\bar{X}$ )	65.625	33.5625
Standard deviation (SD)	12.622	14.315
Sample size (N)	16	16
Normality test KS	0.2002;p=0.0862;passed: Yes	0.1390;p=>0.10;Passed: Yes

The results of the t-test at  $p < 0.05$  show a significant difference ( $t=6.720$ ;  $DF=30$ ;  $p < 0.001$ ) in mean performance of the experimental group ( $\bar{X} = 65.6$  and  $SD=12.6$ ) and the control group ( $\bar{X} = 33.6$  and  $SD = 14.3$ ) in favour of the experimental group in the post response activity 1. The difference in standard deviations is not large. Therefore, this result confirms the positive effects of the SI approach that has brought about an improvement in performance within the experimental groups A and B.

Analysis of practical activity 1 showed that learners in the experimental group developed a clear understanding of the concepts of the topic. In one group sample t-test the experimental group's mean score for practical activity 2 was analysed by column statistics against a hypothetical mean set at 100, using the raw scores in Table 14 since the control group did not carry out this practical activity as a control strategy. The performance of the experimental group,  $\bar{X} = 77.5$  and  $SD=11.9$ , indicates that the group improved its performance from activity 1 ( $\bar{X} = 65.6$ ) by 11.9 percentage points but that its performance decreased by 11.4 percentage points in post-test RBT2, with  $\bar{X} = 80.9$ . The extent of the decrease of 11.4 percentage points in activity 2 relative to post-test RBT2 for the experimental group was determined by the Pearson correlation with values of  $r=0.3517$ ,  $R^2=0.3517$  and  $p=1816$ ,  $p > 0.05$ , which is not significant, suggesting that there was a strong relationship between activity 2 and post-test RBT2 for the experimental group. The results of the Pearson correlation were determined by using raw scores for activity 2 and post-test RBT2 in Table 14 for the experimental group.

#### 4.3.2 Analysis of tests pre-test (RBT1) and post-test (RBT2)

In the third lesson, learners wrote post-test RBT2 on the chemistry of water purification. In RBT2 learners solved stoichiometric problems involving the chlorination of filtered water using bleach to make it suitable for drinking or environmental use as required by Learning Outcome 3 (LO3), (section 2.3) of the National Curriculum Statement (NCS). The answers were marked out of 100. The results in Table 17 show that there were significant differences in performance between the two groups, in favour of the experimental groups A and B, as discussed below.

#### 4.3.3 Welch unpaired t-test for pre-test RBT1: Experimental groups vs Control groups.

The RBT1 (see Appendix 3) was administered to experimental groups A and B ( $N=16$ ;  $\bar{X}=65.44$ ;  $SD=10.28$ ) and control groups C and D ( $N=16$ ;  $\bar{X}=60.44$ ;  $SD=4.21$ ) before instruction. Table 16 shows raw marks of RBT1 for both groups. No statistical difference in mean scores was found between the two groups. ( $t=1.800$ ;  $DF=19$ ;  $p>0.05$  i.e.  $p=0.0878$ ). The 95% confidence interval (CI) of the difference was -10.814 to 0.8139 (see Table 17). Therefore, the post-test scores could be compared using the independent t-test. The unpaired t-test uses Welch correction, which does not assume equal variances.

**Table 16: Raw scores on pre-test (RBT1) for experimental and control groups**

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Experimental	70	75	85	65	80	63	70	69	50	60	60	55	65	58	74	48
Control	55	65	55	60	60	61	58	64	60	65	60	65	61	68	53	57

**Table 17: Pre-test (RBT1) for experimental groups and control groups. (Unpaired t-test)**

Parameter	Experimental groups (A &B)	Control groups (C &D)
Mean ( $\bar{X}$ )	65.4375	60.4375
Standard deviation (SD)	10.282	4.211
Sample size (N)	16	16
Std error of mean (SEM)	2.571	1.053
Normality test KS	0.07947;p>0.10;Passed: Yes	0.1461;p>0.10;Passed:Yes

#### **4.3.4 Independent t-test for pre-test – post-test experimental group.**

Raw scores on pre-test RBT1 and post-test RBT2, in Table 16 and Table 14, sub section 4.3.1 were used to validate the extent of the differences between the means of RBT1 (  $\bar{X} = 65.44$  ) and RBT2 (  $\bar{X} = 80.88$  ) for the experimental groups using Welch correction (see Table 18). The t-test values of DF =29; t=4.244; p=0.0002; p<0.05 indicate a significant difference in means between pre-test – post-test in the experimental group in favour of the post-test (RBT2). Welch's approximate t = 4.244 with 29 degrees of freedom. Mean difference = 15.438 (mean of post-test (80.88) minus mean of pre-test (65.44). The 95% confidence interval of the difference ranges from 7.998 to 22.87.

**Table 18: Pre-test – post-test of experimental groups A and B (Independent t-test results)**

Parameter	Pre-test	Post-test
Mean	65.4375	80.875
Standard deviation (SD)	10.282	10.295
Sample size (N)	16	16
Std error of mean (SEM)	2.571	2.574
Normality test KS	0.07947;p>0.10;Passed:Yes	0.1305;p>0.10;Passed:Yes

In Table 18, descriptive statistics supported by the Welch correction confirm the positive effects of the intervention using SI instruction through practical activity 2 integrating LAM in lesson 2. Practical activity 2 increased performance within the experimental groups A and B as they reached a significantly higher mean of 80.88 in RBT2 than a mean of 65.44 in RBT1. This is a clear signal that the learners' conceptual understanding and knowledge of the chemistry of water purification was enhanced through the inquiry based teaching approach integrating LAM.

#### 4.3.5 Independent t-test for pre-test – post-test control groups (C and D)

In Table 19, the pre-test RBT1 and post-test RBT2 scores for control groups C and D show that no statistical difference in mean scores was found between the two tests ( $t=0.7623$ ;  $DF=30$ ;  $p=0.4519$ ;  $p>0.05$ ). The 95% confidence interval of the difference ranges from -2.099 to 4.599. The mean difference is 1.250, suggesting that the small 1.3 percentage point increase in performance from RBT1 ( $\bar{X} = 60.44$ ) to RBT2 ( $\bar{X} = 61.7$ ) in the control group is not significant. Hence, the traditional teaching material did not have any significant positive effect in terms of performance of learners in the control group but this supports the alternative hypothesis that there is a significant difference in mean performance in favour of the experimental group when taught by the SI approach integrating LAM in practical activities, as analysed in sub section 4.3.4.

**Table 19: Pre-test – post-test of control groups C and D (Independent t-test results)**

Parameter	Pre-test	Post-test
Mean	60.4375	61.6875
Standard deviation (SD)	4.211	5.029
Sample size (N)	16	16
Normality test KS	0.1461; $p>0.10$ ; Passed: Yes	0.1824; $p>0.10$ ; Passed: Yes

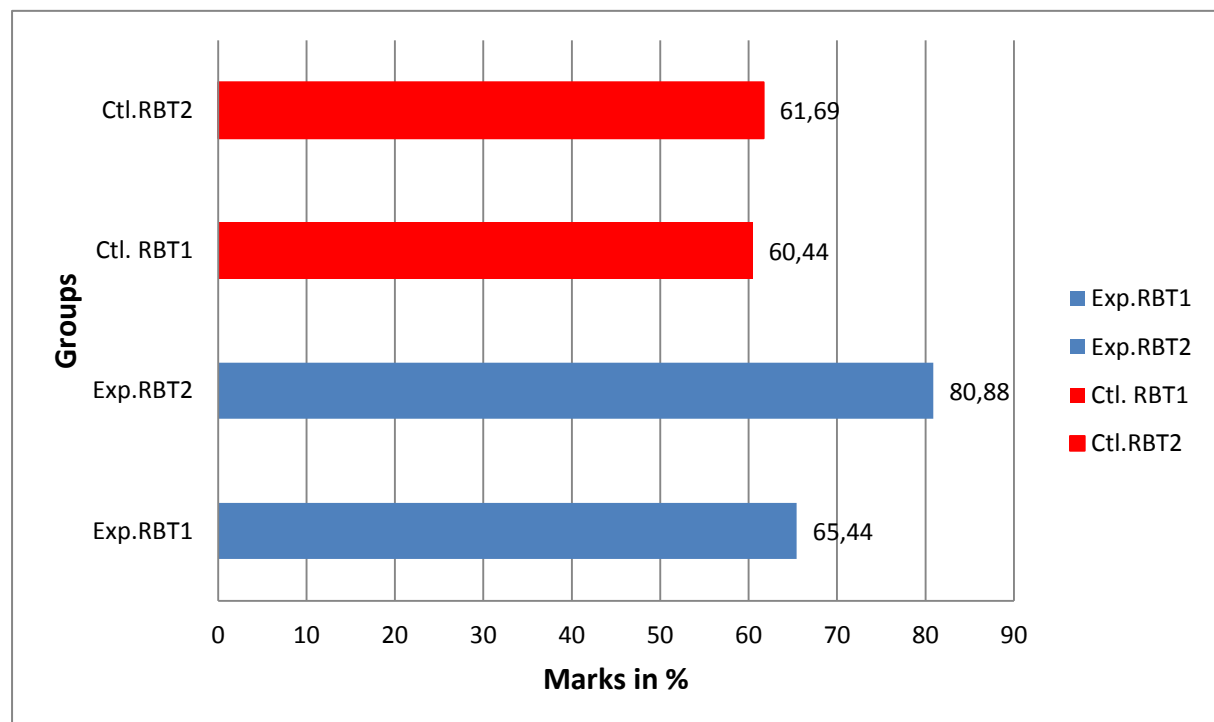
#### 4.3.6 Welch unpaired t-test for RBT2 for experimental groups vs control groups

The RBT2 was administered to experimental groups A and B ( $N=16$ ;  $\bar{X}=80.9$ ;  $SD=10.30$ ) and control groups C and D ( $N=16$ ;  $\bar{X}=61.7$ ;  $SD=5.03$ ) after trials with the activities. The means of the two groups differed significantly in favour of the experimental group with Welch correction applied  $t=6.699$ ;  $DF=21$ ;  $p=0.0001$  hence  $p<0.05$  (see Table 20). The 95%

confidence interval of the difference ranges from -25.144 to -13.231. The mean difference is -19.188, which is extremely large (see Figure 10).

**Table 20: Post-test for experimental and control groups (Independent t-test results)**

Parameter	Experimental group	Control group
Mean	80.875	61.6875
Standard deviation (SD)	10.295	5.029
Sample size (N)	16	16
Std error of mean (SEM)	2.574	1.257
Normality test KS	0.07947;p>0.10;Passed:Yes	0.1461;p>0.10;Passed:Yes



**Figure 10: Graph of means and SD for control and experimental groups (RBT1 and 2)**

#### 4.3.7 ANOVA multiple comparisons of all group pairs for post-test (RBT2)

In the one-way analysis of variance (ANOVA),  $p < 0.0001$  was considered significant suggesting that the SI treatment had a more positive effect on the performance of learners in the experimental group pairs than on those in the control group pairs (see Tables 21 and 23). The Tukey-Kramer multiple comparisons test with  $MS=1208$ ,  $DF=3$  states that if  $q > 3.864$  then  $p < 0.05$  is statistically significant, as shown in Table 23.

**Table 21: Multi Comparison Test (RBT2) of mean and SD among all groups**

Group title	A-Day, urban	B-Day, semi- urban	C-Day and Boarding	D-Day, rural
Mean	87.375	74.375	61.375	62
Standard deviation (SD)	7.633	8.501	5.375	5.071
Sample size (N)	8	8	8	8

Table 23 reveals the  $p$  value to be significant at  $p < 0.05$  in performance in post-test RBT2 between all pairs of groups except for C vs D, which is not significant at  $p > 0.05$ . For group pair A vs B, the mean difference of 13, though not very big, is quite significant in favour of group A. For group pairs A vs C and A vs D, the mean difference of 26 and 25 respectively is very significant, in favour of group A, indicating that this experimental group outperformed control groups C and D. In group pair B vs D, the mean difference is quite significant at  $p < 0.05$  in favour of B, which is also an experimental group. The results of ANOVA in Table 23 for multi mean comparisons of all group pairs were generated through intermediate calculations as shown in table 22.

**Table 22: Intermediate calculations: results of ANOVA**

Source of variation	Degrees of freedom	Sum of squares	Mean square
Treatment (between groups)	3	3622.8	1207.6
Residual (within groups)	28	1291.6	46.129
Total	31	4914.5	

**Table 23: One-way ANOVA results from multi-comparison test for RBT2 of group pairs**

Comparison :Groups	Mean Difference	q	p	Value
A vs B	13.000	5.414	**	p<0.01
A vs C	26.000	10.828	***	p<0.001
A vs D	25.375	10.567	***	p<0.001
B vs C	13.000	5.414	**	P<0.01
B vs D	12.375	5,153	**	P<0.01
C vs D	-0.6250	0.2603	ns	P>0.05

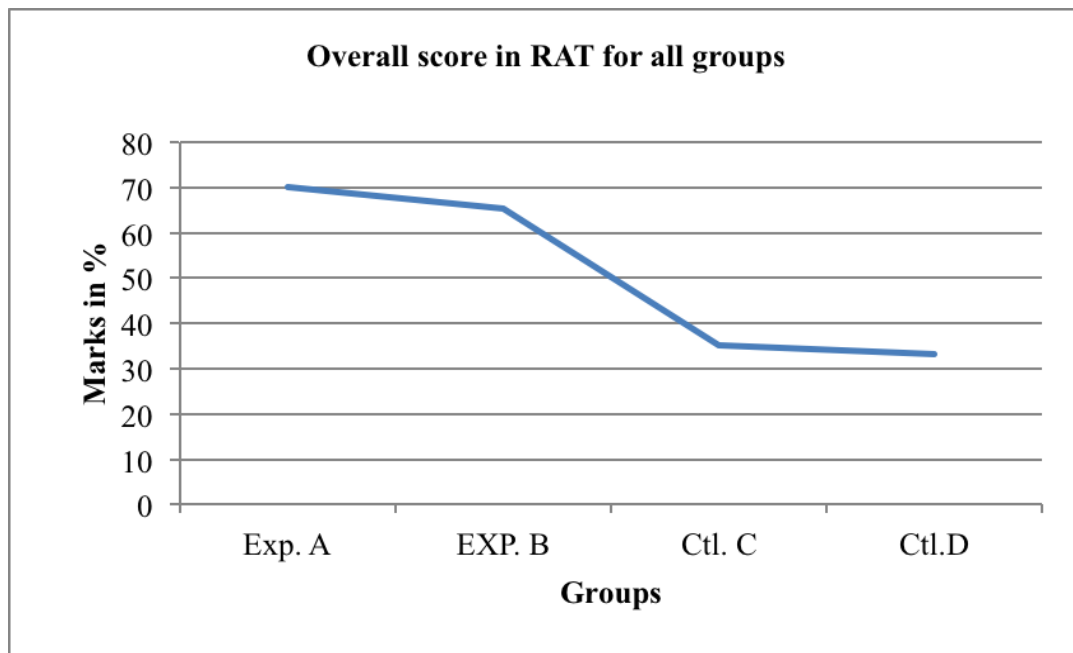
#### 4.3.8 Analysis of activity extension for rubric assessment tool (RAT)

In order to further address sub-question 1(b), which probed how LAM can be integrated into classroom instruction to enhance learners' understanding and knowledge of chemistry of water purification, an evaluation of the activity extension on the innovation of a water purification device provided in lesson 1 (see Appendix 5 and 6 ) was made by the researcher for each group. The learners' innovation title was: *How to apply chemistry of water purification in building of a water purification device at household level using locally available materials (LAM)* (see Appendix 6).

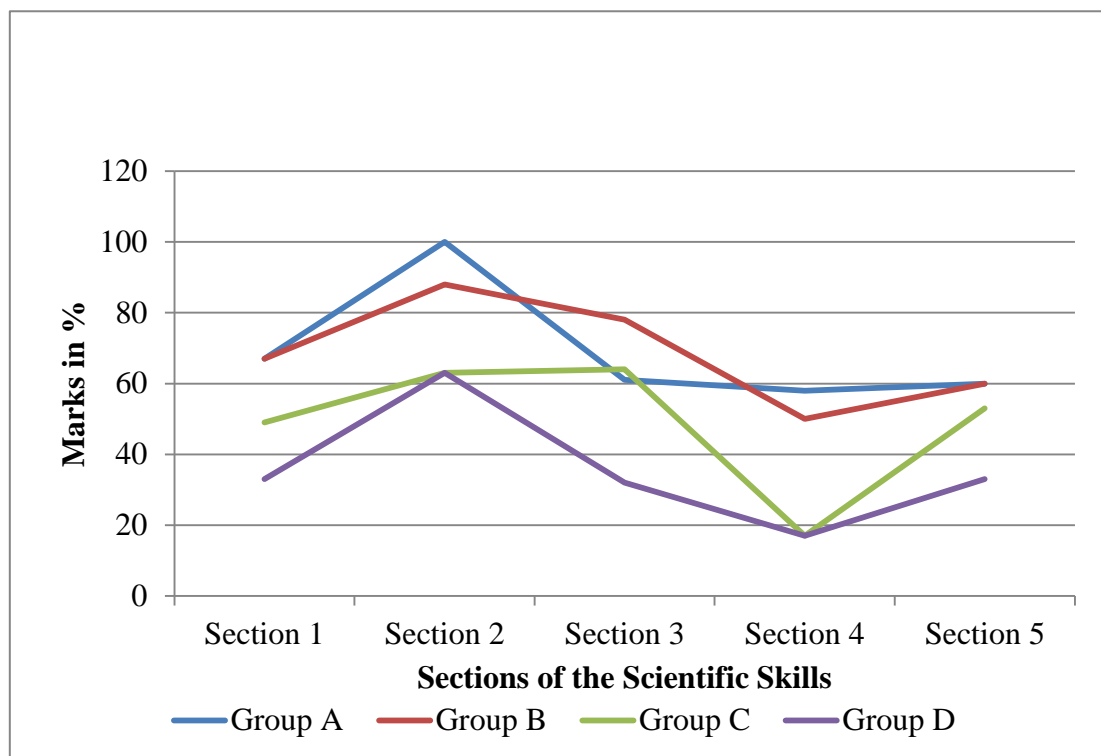
Descriptive statistics in Figure 11 indicate the groups' performance on the innovation project as A (70%), B (65%), C (35%) and D (33%). The relatively higher percentage scores for experimental groups A and B indicate that the SI approach played a more positive role in facilitating the innovation of the device than did the traditional teaching method used in control groups C and D. This means that learners in the experimental groups gained greater conceptual understanding of the descriptive, microscopic (particulate nature of chemistry) and chemical equations of the chemistry of water purification during activities in class as they were able to relate the physico-chemical properties of LAM to water impurities in their design of the device. Learners in control groups C and D had lower percentage scores, possibly because the traditional approach to teaching and learning that was used lacked the practical activities of inquiry into the chemistry of water purification. According to Johnstone (1980), the traditional approach to teaching and learning the chemistry concepts represented (macroscopic, microscopic, or representational) make chemistry abstract and difficult, as observed in the control groups.

Similar patterns in results were also observed for the four groups on the five sections of RAT that were evaluated, with experimental groups performing better than control groups. Group A (100% and 61%) and B (88% and 78%) achieved higher percentage scores than groups C (63% and 64%) and D (63% and 32%) on section 2 (Literature on chemistry of water purification) and on section 3 (Design of device using LAM) respectively. These results indicate that LAM played an important role in increasing learners' understanding of chemistry theory in the classroom and in practice in the laboratory, particularly for the experimental groups (Figures 11 & 12; Table 24).





**Figure 11: Overall performance of all four groups in RAT**



**Figure 12: Groups performance on rubric assessment tool of the device (RAT)**

**Key:**

Section1: Introduction/Background

Section 2: Literature Review/Innovation focus

Section 3: Research Methods (Design)

Section 4: Discussion (Originality and functionality)

Section 5: Conclusion (Oral presentation and write-up)

#### **4.4 Implications of Findings**

Question 8 in the questionnaire and question 10 in the interview probed the 32 sampled learners on problems they experienced when learning water purification, particularly those concerned with chemical equations that occur at each stage of the process. More than 50% of the learners felt that their difficulties had multiple causes, the major ones being teachers' incompetence, a lack of apparatus and chemicals, irrelevant textbooks that did not relate theory to practice, and traditional approaches to teaching that simply replicate textbook experiments and highly structured topics. They felt things would be better if teachers were more resourceful and used innovative instruction approaches such as the SI method used in this study to support their teaching with LAM. This would motivate most learners intrinsically and help them to relate to and recall the chemistry concepts they covered in the classroom. Based on this finding, it is clear that when learners are taught through SI integrating LAM, they develop the critical thinking and argumentative skills necessary to solve authentic scientific problems, and this enables the creation of future scientists.

#### **4.5 Discussion of Findings**

##### **4.5.1 Difficult nature of chemistry**

The main purpose of the study was to investigate whether teaching chemistry of water purification in Grade 11 using LAM through the SI approach rather than through a traditional teaching approach would help to improve learner performance. Clow (1998) notes that an understanding of how learners learn can help teachers to design effective strategies for teaching and learning. For this reason the researcher needed to acquire knowledge of learners' prior understanding of the chemistry of water purification, as described by McDermott (1984). This information was very important since studies have revealed that abstract concepts are central to further learning in chemistry and other sciences (Coll and Treagust, 2001a; Nicoll, 2001; Taber, 2002). Several research reports have revealed that concepts and

phenomena in chemistry are abstract and difficult and can only be learnt through the use of chemical representations (Hilton, Nichols & Gitsaki et al. 2010). Therefore any misconceptions and alternative conceptions that learners have about these concepts of microscopic matter will impede their further learning of chemistry (Gupta-Bhowon et al. 2009; Simsek, 2009). Taber (2002) and Zoller (1990) observe that chemistry classes demand high-level skills since the abstract nature of chemistry makes it a difficult subject for many learners to understand.

Ayas, Köse and Taş (2002) noted that problems worldwide such as overcrowding, lack of materials, inadequate laboratories, and poor teacher preparation are also experienced in the study context. The researcher had to be resourceful and use chemicals such as, alum and litmus paper or universal indicator, plastic bottles and filter media in order to carry out the practical activities in the classroom. The majority of learners in the study preferred engaging in practical activities when learning the chemistry of water purification. This is supported by research studies by Grouws and Cebulla (2000) and Ingvarson et al. (2004), which revealed that teaching practices that offer learners opportunities to learn using experiments and activities are related to better learner performance. In Grade 10, basic concepts such as the structure and physico-chemical properties of water are taught. Most Grade 10 learners are unable to develop the advanced intellectual and conceptual skills and knowledge central to solving problems related to the chemistry of water purification. For this reason, in Grade 11 high mental models (Taber, 2002), particularly descriptions of chemical equations and equilibria, and the enhancement of learners' conceptual understanding (Harrison & Treagust, 2000) become sources of difficulty for many learners of chemistry. In Grade 11, parts of the chemistry of water purification such as redox reactions, acid-base systems and pH, precipitation reactions, chemical equilibria and stoichiometry are all highly conceptual and abstract, as observed by Taber (2002).

The results of this study indicate that important concepts of redox reactions and precipitation reactions of ions into higher oxidation states had not been grasped sufficiently by the learners, as reported by Taber (2002) and Coll and Treagust (2001a). This finding, though not validated owing to the small sample size, is similar to that of Zoller (1990) and Abraham et al. (1992). These scholars found that chemical change and chemical reactivity and balancing redox equations were difficult mental concepts for learners to master.

Solution chemistry involving hydration, dissolution and hydrolysis of impure gases HCl and H<sub>2</sub>S in water and a shift in the chemical equilibrium to the left to remove the gases through dehydration is a source of great conceptual difficulty for learners (Çalık et al. 2005, 2006). The findings that a significant number of learners in this study had difficulties in understanding hydration and hydrolysis in solution chemistry are similar to those of Çalık et al. (2005, 2006). Learners also needed to increase their understanding of pH dependent equilibria and precipitation and the coagulation of particles in dirty water through practical activity 2 as carried out in lesson 2 (Appendix 7). Many learners had difficulty learning the chemistry of chlorination, particularly the understanding of chemical and ionic dissociation equations and formulae. There have been a number of studies that address problem areas of learning concepts of acids and bases. Many of the topics that learners have difficulty with and misconceptions are basic to chemistry knowledge and are interrelated. These findings support many studies which address the difficult aspects of learners' understanding of acids and bases as reported by Dermircioglu et al. (2004).

Themes and patterns emerging from the analysis of open questions numbers seven, eight and nine for learners (see Appendix 1) suggest a more practical approach to learning the chemistry of water purification in the classroom will enhance the understanding of concepts in a real and meaningful way. Learners do not understand the chemistry concepts properly when taught through a traditional approach that is teacher-centred and follows strictly the structured sequence of abstract chemistry topics in the textbooks. The understanding of chemical equations, chemical equilibria, formulae and reactivity were rated the most difficult, while, somewhat surprisingly, chlorination chemistry was rated the least difficult, possible because learners interpreted it from a non-scientific point of view, notwithstanding that it is a chemical concept of acid-base systems and chemical equilibria. Many learners noted that chemical equations of water purification were difficult to understand, pointing to the need for a theoretical and practical approach in learning and teaching if meaningful understanding is to be achieved in the classroom. Brody (1993) has observed that learners hold onto their views of the common phenomena of water that they have acquired through personal experience even after instruction. Of particular concern was the fact that most learners were unable to explain the relationship between water impurities and the use of LAM to remove these impurities, or to classify them as physical, biological or chemical contaminants.

Learners' responses suggest that practical tasks such as research projects, experiments, and chemistry-based educational tours are the most dynamic and productive approaches to teaching and learning chemistry. In order for topics such as acid-base reactions, chemical equilibria and redox systems to be sufficiently understood in classroom instruction, the chemical processes of water purification such as dissolution, precipitations, redox systems, hydration, hydrolysis, and adsorption are some of the fundamentals that must be understood during practical activities, as observed by Çalık et al. (2005). The majority of learners did not understand the topic adequately since they had gaps in their background knowledge for various reasons, amongst them teachers' lack of knowledge of SI and LAM, the shortage or absence of practical infrastructure in schools and the thought of chemistry as a being a complex subject that is in conflict with the cognitive needs of learners and conventional instruction currently applied by teachers in the classroom. Many learners have difficulties in visualising atoms, molecules and ions in three dimensions and in understanding various chemical phenomena (Tsaparlis, 2003; Mahafy, 2005). This research study thus tried to fill this gap using SI instruction that integrated LAM in an effort to help learners to understand difficult concepts related to water purification. Visual chemical reactions at each stage of water purification using LAM that are familiar to learners will help in the teaching of important scientific concepts in chemistry.

An analysis of learners' responses to the questionnaire and interview and the relevant literature identified the following problem areas in the learning of the chemistry of water purification:

- Redox reactions that result in precipitation and removal from water of  $\text{Mn}^{2+}$  and  $\text{Fe}^{2+}$  ions into higher oxidation states of +7 and +3 respectively during aeration.
- Hydration and hydrolysis (dissolution) of HCl and  $\text{H}_2\text{S}$  gases in water during aeration, hence their escape from water by a shift in equilibrium to the left, caused by dehydration.
- Acid-base systems and pH dependent equilibrium and precipitations of metal ions such as  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  ions that remove dirty particles in water during coagulation, turning water clear.
- Chemical formulae, balancing chemical equations, chemical and ionic equilibrium and acid-base systems of the chemistry of chlorine in water were rated the most difficult

concepts by learners. Examples of difficult concepts reported are: hydrolysis of  $\text{Cl}_2$  in water, pH dependent dissociations of hypochlorous acid ( $\text{HOCl}$ ) and of hypochlorite ions ( $\text{OCl}^-$ ) in water in order to yield more  $\text{HOCl}$ , which is a stronger disinfectant than  $\text{OCl}^-$  and stoichiometry to determine the amount of bleach needed to disinfect a certain volume of water filtered in the laboratory during the building of the water purification system by the experimental group.

It also emerged that as teachers focused on “covering the syllabus”, they failed to use LAM and local resources, further aggravating the difficulties learners experienced in learning science. Therefore, home and real life examples incorporating science in the community in school science would help the learners to remember what they are taught. The study revealed that as the teachers confined themselves to textbooks, they ignored experiences learners brought from their communities.

#### **4.5.2 Effects of Scientific Inquiry (SI) Instruction**

As expected, the learners in the experimental groups who were taught through SI scored significantly higher on the post-test RBT2 when compared to the control groups who received their lessons through a traditional teaching approach. The pre-test and post-test measured the performance level of both the experimental and the control groups. The findings revealed that teaching that integrated LAM achieved better results in the post-test for the experimental group than for the control group. Thus SI instruction had a greater effect on the performance of learners. A possible reason for the higher mean score for RBT2 for the experimental groups could be that these learners understood and performed better when they performed the activity practically (Nui & Wahome, 2005). The researcher’s direct actions of practice with participants in the experimental groups using “productive” questioning improved performance as observed by Dick (2002). The findings also suggested that most learners in the experimental group were happy and changed their perceptions of chemistry as a difficult subject. The difficulties that were checked up on in the analysis of the answers to questions about activity 1 showed that particularly the control groups C and D found some chemistry concepts difficult. Examples of such concepts were precipitation of metal ions into higher oxidation states during the coagulation process in water, hydration and hydrolysis of impure gases during aeration processes in water and disinfection of water by chlorination. These difficulties were overcome in practical activity 2 by integrating LAM that were

familiar in the daily lives of learners, such as sand, stone and gravel and crushed glass for the physical filtration of solid particles, charred vegetation for active adsorption of contaminant metal ions by chemical filtration, household bleach for the biological disinfection of water by killing pathogenic organisms and plastic bottles as filtration tanks. The inclusion of these LAM in practical activity 2 enhanced the understanding of the experimental group learners in RBT2 ( $X = 65.6$ ) as they performed significantly better than control groups ( $X = 33.6$ ) where similar LAM were not used, and where traditional problem solving skills and a chalkboard approach without practical activities was followed instead. In addition, the researcher explained the basic aquatic chemistry as taught in lesson 1 (see Appendix 5) such as the molecular structure of water, physico-chemical properties of water (polarity, solubility and conductivity), acid-base system and theories and chemical and ionic equilibria of weak acids and bases, precipitations, and redox systems, in an effort to enrich learners' understanding of chemistry concepts related to practical activity 2 dealing with water purification.

In lesson 2 (Appendix 7), practical activities comprising the building of a simple water purification system using LAM defined the logic of chemistry and the cognitive needs of the learner. This study utilised a learner-centred approach grounded in constructivist perspectives, in which the order and presentation of the practical activities through an SI approach reflected the psychology of the learner, as noted by Johnstone (2000). According to the apprenticeship model, similar to constructivism, the learners in the experimental groups who were taught using the SI approach as well as those in control groups who were taught through a traditional approach developed skills and a better understanding through their interaction with their more skilled teachers within the context of a socio-cultural activity (Rogoff 1990:7), as noted in sub section 2.8.3.

At the end of practical activity 2, in-class discussions took place under the guidance of the researcher to encourage learners to suggest how their difficulties could be solved by the outcome of the activity. However, some learners in the experimental group did not improve significantly in their performance after trials with activities. As Bodner (1991) has observed, even some graduate learners with a major in chemistry face difficulties in applying their knowledge and extending their knowledge into the world. The results in Figure 10 illustrate that through increased treatment, all groups improved with the experimental group performing relatively better than the control group, a finding that is similar to that observed

by Becker et al. (1980) and noted in sub section 3.1.2. Similar studies which support investigations such as the one by Becker et al. (1980) and the findings of the present study are discussed here. It is argued that in a problem solving or inquiry learning environment, learners attain either slightly higher scores than learners in a conventional approach, or at least similar scores (Miller, 2003; Rideout, England-Oxford, Brown et al., 2002). The present results confirm this view.

Miller (2003), Rideout et al. (2002) and Soderberg and Price (2003) reported that learners in inquiry-based studies perceived their learning environments to be more positive than their counterparts in conventional programmes. Treagust, Chittleborough and Mamiala et al. (2003) found that chemical knowledge is learnt through the chemistry triangle represented by the three abstract levels of the macroscopic (descriptive), microscopic and representational worlds. In a related study, Gabel (1993) investigated learners in an introductory chemistry course. The experimental group received additional instruction on relating the particulate nature of matter to other levels (macroscopic and representational levels). Gabel found that this group similar to the one in this study performed better than the control group at all levels. Once learners in this study had collected and recorded their literature on the chemistry of water purification, difficulties arose when they were unable to apply chemistry to the different stages of water purification, as observed by Choksi et al. (2006). According to Harlen (2001), the questioning strategy employed by teachers, apart from supporting the learners in their investigation, also develops the habits of reflection and self-criticism in learners. Chin and Osborne (2008:1-39) note that “Investigative questions do not emerge spontaneously from learners (although learners are curious) and teachers have to employ strategies to elicit these”

Yuzhi (2003) investigated the application of inquiry-based learning in the teaching of analytical chemistry concepts such as chemical and instrumental analysis. Learners' performance was subject to the reports they prepared after the study and examination at the end of the trial. It was found that the experimental group was more successful in the use of laboratory equipment, problem solving and understanding of theory than the control group. However, there was no statistically significant difference between learners' performance on the written examinations. Similar studies in analytical chemistry have been conducted by Ram (1999) and Ying (2003). Their results support the findings of the study reported on in this dissertation, that inquiry-based instruction integrating LAM prepares learners for solving



everyday life problems using chemistry and enhances their understanding and knowledge of chemistry.

Although a statistically significant difference between the total mean scores of the SI and traditional instruction was found in the present study, it was not as large a difference as shown by the analysis of the unpaired t-test models of the experimental and control groups on pre-test RBT1 and post-test RBT2 (see Tables 17 and 18). However, these data indicate that the SI approach may be at least as effective for teaching chemistry as traditional lessons. Moreover, it is also argued that the significant effect of the approach appears to be the learners' satisfaction with the learning environment. An item analysis of open-ended questions in RBT2 showed an interesting similarity amongst the experimental group learners regarding correct answers. Their answers were more accurate and more precise than those of the control groups and their explanations were supported by arguments including examples. It could be concluded from this finding that the experimental group learners scored higher in the performance tests after completion of the “treatment”. This was evidenced by the fact that even after four months, learners in the experimental groups achieved higher mean scores in their groups’ innovative research project of building water purification devices for use at household level. Relatively high mean scores for experimental groups A and B in RBT2 (see Table 20) and in RAT (see Figures 11 & 12) point to the fact that learners experienced a constructivist environment and had the opportunity to develop interpersonal skills through problem solving. These findings are similar to those of Chin and Chia (2004), who noted that learners in inquiry learning are actively involved and learn in the context in which knowledge is to be applied, as noted in the discussion of constructivist perspectives in sub sections 2.8–2.8.2. The reason for the poor performance in control groups C and D in RBT2 (see Tables 19 & 20 and Figure 10) and in RAT (see Table 24 and Figures 11&12 ) could be due to a lack of active participation in the acquisition of the knowledge necessary to solve and apply the chemistry of water purification. The low mean scores of the control groups indicate that the SI approach may have contributed significantly to the knowledge and understanding of the chemistry of water purification in line with all the learning outcomes of the NCS, as the experimental group reached a higher level in the post-test (RBT2) and post-response test RAT. Table 23 illustrates the statistical significance in the difference in the means of groups A, B, C, and D; although this difference in means is not very large, the p values clearly confirm the results reported in Figure 10, which shows the graph of means and

SD for control and experimental groups for pre-test and post-test independent t-test in sub sections 4.3.4 and 4.3.5. From this it is possible to say that SI that integrates LAM has a greater effect on learning the difficult concepts of chemistry as it increases learners' interest and motivates them.

#### **4.5.3 Discussion of the water purification devices realisation test (RAT)**

Learners including those who are “talented” require substantial training to attain skills. Furthermore, “deliberate practice” involves learners' curiosity about their assessment to check on their improvement (Donovan & Bransford, 2005). In the SI approach, feedback is given on worksheets and interviews and oral presentations, written reports and in the form of the RAT that uses a detailed checklist (Table 24 & Appendix 9). Skills in presentational knowledge are crucial for pedagogical value of practice and formative assessment. In the absence of presentational (writing) skills training and assessment, learners are worried about their writing reports. Reports often provide summative assessment, without much “practice” in writing skills. Furthermore, the value of writing as a way for thinking about chemistry and organising information (Ellis, 2004) was clearly appreciated in this study by the two experimental groups, A and B.

The design of the water purification device was elaborated on through the contextual nature of the topic, “Water Purification” and through continuous justification of the appropriateness of LAM and methods. Communication and collaboration occurred at intragroup and intergroup levels (Choksi et al., 2006). Learners practised skills and tool use procedures in authentic problem solving settings, as described in the research design (see sub section 3.2.3). As learners practiced their ideas in the course of posturing and investigating a theory (hypothesis), they followed a procedure that led to a deeper conceptual understanding of the chemistry of water purification (Marzano, Pickering, & Pollock, 2001). This is illustrated by pictures of the prototype water purification devices at household level using LAM (see Figures 13, 14, 15 and 16). The performance of each group as illustrated in RAT (see Appendix 9, Table 24 and Figures 11 and 12) in the realisation of the device using LAM is summarised for each group. The five skills/characteristics of the SI (Table 24) were summarised from the RAT in Appendix 9. For each group each skill was marked out of a possible mark, and converted to 100% for group comparison purposes. Using descriptive statistics the percentage score for each skill for each group was generated to obtain the

overall percentage score in RAT that was compared to the actual percentage mark based on marking. Research design and methodology carried the highest possible marks in RAT because learners' autonomy is demonstrated most in these characteristics of SI. The main focus for assessment was on the literature search on the chemistry of water purification, generating hypotheses, the choice of LAM and the design and technology of the device.

**Table 24: Summary of the raw scores in percentages in RAT in five chapters of the project**

Skills	Possible mark	A mark	A %	B mark	B %	C mark	C %	D mark	D %
1. Introduction: background; problem statements; hypothesis	24	16	67	16	67	11	49	8	33
2.Literature review/development/ focus on application of chemistry of water purification	8	7	100	8	88	5	63	5	63
3. Research methods: realisation/production of unit i.e. plan, design, & construction of device	41	32	61	25	78	9	64	13	32
4. Discussion/data analysis: originality, functionality of unit	12	6	58	7	50	2	17	2	17
5. Results and conclusion: oral presentations; project write-up	15	9	60	9	60	8	53	5	33
Total	100	70	346	65	343	35	246	33	178
Average % (n=5)	100		69.2		68.6		49.2		35.6
Actual % (Marked scripts)	100		70		65		35		33

## Realisation of the device by Experimental Group A



**Figure 13: Realisation of device by Experimental Group A**

Overall score: 70%

### Abstract:

Learners developed a water purification device that re-uses grey water from the bathroom and from washing laundry to flush toilets, to water gardens and to wash cars. The device (Figure 13) includes three plastic bottle chambers (upper, middle and lower) connected by hard polyvinylchloride (PVC) pipes that are held in position by a wire frame. Gravity forces the flow of water through the pipes from the highest to the lowest chamber. The grey water is poured into the top chamber and as it flows from chamber to chamber, the water is filtered.

### Chapter 1: Introduction (67%)

Research questions were very clear as they addressed how and which LAM to use to construct the water purification device, and also the benefits the device held for the community in terms of saving water by “recycling”. The problem statement was unclear, as it

was not directly linked to the innovation topic, but was aligned more to the narrative approach of saving water at community level.

The hypothesis, like the problem statement, was stated but not clearly related to the innovation topic, as it related to how the community could save water by using the device.

#### Chapter 2: Literature review (100%)

The literature review was relevant and related very well to the chemistry of water purification. Learners were able to identify the problems of water scarcities, rationing and recurrent droughts which lead to the need to seek innovative ways of reusing grey water at household level by applying the classroom chemistry of water purification in their design. Learners acknowledged that expensive systems currently exist, so the use of affordable and available LAM in the design and technology of the present device was a new approach.

#### Chapter 3: Research design and methodology (61%)

In response to the treatment from the SI approach, the classroom chemistry lessons on water purification and the activities (pre-laboratory and pre-research lesson), the learners developed the device as shown in Figure 13. It was assembled from LAM and used three 2-litre plastic bottles connected with pipes. The device is held in position by a wire frame. The design was clearly and correctly labelled, but it lacked scale measurements of length and breadth.

The three chambers represent different stages in the filtration process. The first chamber is a sand filter chamber which removes insects, small organisms and some solids. The second chamber is a carbon filter for removing chemical impurities. The third chamber is used to chlorinate the water to deactivate pathogens.

In summary, the group followed the instructions accurately and independently as presented in the innovative research project task in lesson 1 (Appendix 6). Learners also used the apparatus safely, recorded their findings correctly and controlled all the experimental variables well.

#### Chapter 4: Discussion and data analysis (58%)

As indicated in Figure 13, the device is a simple apparatus assembled from LAM and guided by classroom chemistry of water purification. The device is constructed of inexpensive LAM

and serves its simple purpose of purifying grey water. The device is made to proportion, portable, but its appearance is not appealing in terms of size, colour and shape.

#### Chapter 5: Results and conclusion (60%)

This group demonstrated their skills in the project write-up and oral presentations as already alluded to in Section 4.3. Learners used the correct and relevant sources. Learners stated that further chemistry studies at university would enable them to purify water adequately for drinking purposes. The group was unable to meet regularly owing to formal classes and long distances between their homes. Volume measurements of water and chemical samples and chemical tests for water impurities were estimates (hence inaccurate), a result of the absence of laboratory facilities.

#### Realisation of the device by Experimental Group B



**Figure 14: Realisation of device by Experimental Group B**

Overall score: 65%

#### Abstract:

This grey water purification device uses gravity to move water from the top chamber into the lower ones. The design consists of three plastic bottle chambers assembled from LAM that

represent three filtration processes, namely a sand filter for removing solids, a charcoal filter for removing chemical impurities by adsorption, and a chlorination chamber to kill pathogens.

#### Chapter 1: Introduction (67%)

Three research questions were formulated, but two of them did not clearly address the device topic, as they were more aligned to the causes of water scarcity and wastage, rather than to how chemistry of water purification could be applied in the design using LAM.

Problems relating to water scarcity, municipal rationing and periodic droughts were indicated and directly linked to the need to make the prototype device. The variables for the device procedure were correctly identified as time (independent), LAM, chemistry knowledge of water purification and skills (dependent) and volume and area measurements (controlled).

The hypothesis for the device failed to specify the variables, as it focused more on the value of the device to the community as opposed to the application of the chemistry of water purification in the design.

#### Chapter 2: Literature review (88%)

Related literature on the device was very relevant and closely linked to the research questions, specifically the societal value of the device. Learners referred to literature to acknowledge that saving water at household level using the device is not an invention, since it has been in use in the USA and Australia for many years and is growing in popularity in South Africa.

Using the available literature, the learners identified three stages of water purification in line with the availability of LAM, namely a sand filter, a carbon filter and chlorination.

#### Chapter 3: Research design and methodology (78%)

In the production of the device, learners first drew a linear flowchart describing the design of the device and illustrating the three major purification stages. These were linked by flow arrows from the top to bottom chambers, so that water could flow down the system by the force of gravity. Learners explained, where possible with chemical equations, the processes occurring at sand filtration, as physical separation of removing solids from water; carbon



filtration as chemical adsorption of metal ions in water; and chlorination as biological killing of pathogenic organisms.

The flow chart was clear but lacked a scale for the plan, therefore it was not a schematic embodiment of the device. Nonetheless, it was a good attempt to clearly illustrate water processes of water purification in a mind map.

The group followed the instructions in the innovative research project task (Appendix 6) and they gained sufficient conceptual knowledge and understanding of the chemistry of water purification from lesson 1 (Basic aquatic chemistry and chemistry of water purification) (see Appendix 5) and lesson 2 on practical activities in the building of a water purification system using LAM (see Appendix 7). The group was therefore able to work safely and to control the variables independently.

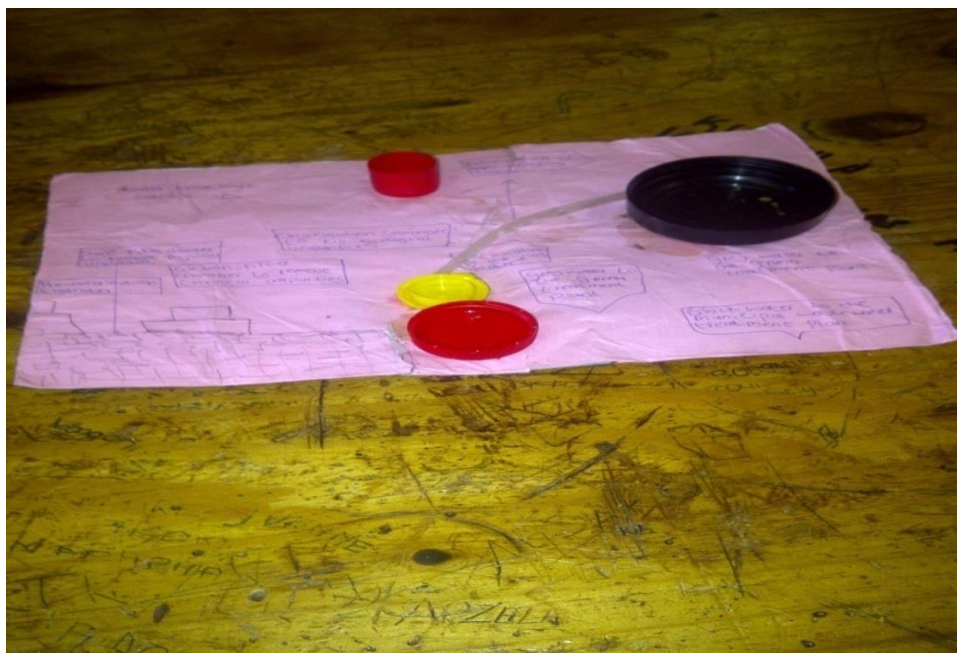
#### Chapter 4: Discussion and data analysis (50%)

The device is portable, user friendly and in working order. Appearance in terms of shape, colour, and size is relatively attractive. The product is made of LAM and serves its purpose of water purification at household level (Figure 14).

#### Chapter 5: Results and conclusion (60%)

This group demonstrated their skills in the project write-up and they became adept at conducting literature searches on the chemistry of water purification. The group experienced limitations in terms of inadequate laboratory apparatus and chemicals for testing the water quality. They recommended taking the research further to university level chemistry to purify grey water for drinking purposes using UV treatment and reverse osmosis.

Realisation of the said device by Control Group C



**Figure 15: Realisation of device by Control Group C**

Overall score (35%)

Abstract:

The summary of the device was unclear. The topic related broadly to “saving water at household level” instead of focusing on how chemistry of water purification could be used to make the device. The approach was narrative, as opposed to the making of the device using LAM.

Chapter 1: Introduction (49%)

The problem statement was present, but vague. The problem of water shortages as the result of periodic droughts and “abuse of water” was implied, but it was not clear how the device would resolve the issue.

Research questions followed a narrative approach and addressed the importance of saving water at home, but this discussion was irrelevant to the anticipated research design of the device. An incorrect hypothesis was generated and no variables were identified. Therefore, the orientation of the device process was off course and out of context.

## Chapter 2: Literature review (63%)

The learners focused on the narrative part of the device, mainly what the community could do to save water at household level and how this could be done. These questions guided their literature search but were irrelevant to the topic which required learners to apply the chemistry of water purification to the realisation of the device. The learners also wrote in detail about saving water at municipal level, which could be regarded as related literature complementary to the design of the device. However, the project focus should have been on chemistry of water purification and the making of the device using LAM, instead of on water saving strategies at municipal level.

## Chapter 3: Research design and methodology (64%)

The design of the device in the form of a flow chart was copied directly from the model picture of a household water purification device (Appendix 4) handed out by the teachers during conventional classes. The model consists of three chambers filled with sand, carbon, and chlorine. The drawing of the design is not to scale and it is not a schematic embodiment of the device.

Learners could not follow instructions to procedures independently as they were presented in the innovative research project task (see Appendix 6) and could not identify any variables. The materials collected (paper, stroke pipes and sand) were suitable for constructing the design model, but not the actual device. The description of the embodiment of the device in the form of a design using LAM is shown in Figure 15 and comprises three chambers with a sand filter, a carbon filter and a chlorination chamber.

## Chapter 4: Discussion and data analysis (17%)

The objective of realising a functional device was not achieved, but was limited to a design model using LAM. This suggests that the learners could not work independently without some intervention in the form of extra instruction using the SI approach that had improved the performance scores of the experimental groups. The innovation did not move beyond the design stage and indicated to some extent the absence of LAM and a lack of conceptual understanding and knowledge of the SI method and the chemistry of water purification relevant to the topic.

## Chapter 5: Results and conclusion (53%)

The project write-up was very poor with many grammatical, spelling and scientific errors. Irrelevant literature sources were used without acknowledgement. The discussion and conclusion were not related to the hypothesis

Realisation of the device by Control Group D



**Figure 16: Realisation of device by Control Group D**

Overall score: 33%

Abstract:

The water purification device was constructed using three chambers in a vertical arrangement. From the top to the bottom chamber, this represented the three stages of purification of grey water, namely a sand and stone filter with a plastic bottle for removing solids on top, a plastic bottle filled with charred vegetation for removing chemical impurities, and a plastic bottle containing bleach for killing pathogens. The summary did not indicate how the hypothesis and research questions were answered.

## Chapter 1: Introduction (33%)

The problem statement was broad and vague: “How can water problems be stopped?” It was not linked to the device variables. The research questions were present, but irrelevant to the topic, since they related to how and what people should do to save water. There was no mention of the making of the device in the research questions. The generated hypothesis and identified variables were out of context, as they were not related to the topic. However, they supported the narrative approach of the research.

## Chapter 2: Literature review (63%)

The literature review took a narrative approach, similar to Chapter 2 of control group C. It focussed on large scale water purification at municipal level. However, the process chemistry of water purification (namely a sand filter, a charcoal filter and chlorination) were identified as the main stages in the realisation of the device.

## Chapter 3: Research design and methodology (32%)

The device in Figure 16 was constructed without a design plan or drawing. Learners did not present a plan to collect, record or analyse data. They thus did not follow instructions independently as required in the innovative research project task (see Appendix 6), as supported by the model diagram of water purification at household level (see Appendix 4). However, marks were awarded for the use of LAM to make the device.

## Chapter 4: Discussion and analysis of invention (17%)

Although the device was developed, its presentation in the form of a design was not satisfactory. The device consists of three two-litre plastic bottles in a vertical arrangement connected by plastic straws.

Although the learners assembled the device according to the model diagram provided, they failed to explain the chemical processes that occurred at each stage, namely the sand and stones in the top chamber filtering solids, the middle chamber containing charcoal for the removal of chemical impurities, and the bottom chamber for chlorination.

In addition, the learners failed to explain that the force of gravity was responsible for the downward flow of water into the chambers. In fact, the learners did not attempt any meaningful discussion and analysis of the innovation, which led to their poor marks.

#### Chapter 5: Results and conclusion (33%)

The write-up was very poorly organised and included many grammatical, spelling and scientific errors. Furthermore, incorrect referencing techniques were used, indicating that this group did not participate in the intervention, which was the causal factor in the better performance of the experimental groups.

Therefore, having successfully made the device, the group did not understand the chemistry concepts and processes underlying this device, as evident in its incomplete design.

#### **4.5.4 Discussions of the researcher's informal interviews with learners and teachers**

Feedback from the experimental group work projects was positive overall. Learners appreciated the chance to make an input to the learning material. The introduction of oral presentations may have been useful to learners. However, with class sizes of over 80 learners, as in most historically segregated urban and rural schools, this is probably not practical given the time constraints, as the process would be difficult to assess and coordinate. Overall, this teaching technique promotes long-term motivation and learning. Responses during action visits and presentations indicated that this was the first time learners had encountered such an approach and they were motivated to study as they realised that they could do something themselves. The SI approach also helped learners to realise that chemistry is a real part of their everyday life, as can be seen in this quote:

"I am now an inventor scientist. I want to save water using local materials and classroom chemistry in my community".

In addition, this new approach helped to develop group work skills:

"Working in groups helped us to gain responsibility and ownership. Failure of the group is also my failure we had to push through discussion opportunities."

Moreover, learners stated their satisfaction with the SI approach and mentioned that it was what they were expecting at university. This can be seen from the following quote:

“This is new and no ordinary learning. This is what we call chemistry for life.”

Informal interviews with teachers showed that their main goals for physical sciences courses were to help learners pass the Grade 12 Matric examination to qualify for Bachelor's degree entrance at university. Most teachers reported that they mostly conduct physical sciences lessons in the classroom setting using a traditional teaching approach and rarely use the laboratory even if it is available. The teachers encouraged learners to solve multiple-choice questions and past examination questions to prepare themselves for promotion to Grade 11 and for passing the Matric examination in physical sciences.

#### **4.6 The main research question on features of an effective teaching approach**

The following main research question was addressed in this study:

1. *What are the features of an effective approach to teaching water purification to Grade 11 learners using locally available materials (LAM)?*

Analysis of data in Chapter 4 has shown that SI instruction used in this study has the following attributes:

- 1) SI instruction is intrinsically motivating as reported in this study and in a number of others cited in sub sections 4.3.1 and 4.3.6, since learners developed higher cognitive skills in problem solving in real life contexts using LAM.
- 2) SI activities explicitly teach the three levels of thought of chemistry represented by the chemistry triangle of “macroscopic”, “microscopic” and “representational” levels. These are a source of difficulty for many learners. The SI approach distinguishes the difficult interplay between them and enhances understanding and knowledge of chemical concepts of water purification such as aquatic chemistry, redox reactions, acid-base systems, precipitations, and equilibria (Treagust et al. 2003).
- 3) The SI teaching approach presented a “good problem” on the chemistry of water purification that could be solved using real life experiences by learners through practical investigations using LAM, which are readily available (Appendices 6 & 7; sub sections 4.2.3 & 4.3.8).

## **4.7 Implications**

The use of SI instruction integrating LAM in classroom learning has several implications for learners' academic performance. Learners can gain better conceptual understanding of the difficult concepts of chemistry through the interaction of LAM. Learning through SI increases learners' interest and motivation to learn and makes descriptive chemistry concepts observable, simple and understandable. It increases learners' reasoning or argumentative skills, particularly in the context of real world problems. It places the learner at the centre of learning and teaching, promotes learners' autonomy and provides a collaborative learning environment, consistent with constructivist learning theory. Thus, from this research finding it is possible to say that SI that integrates LAM provides learners with the opportunity to experience what scientists undergo when they are solving an authentic scientific problem in a professional laboratory, guided by the rigorous scientific inquiry process. At school, scientific inquiry that solves authentic problems in an inquiry laboratory builds on learners' higher cognitive knowledge skills levels, filling the gap in creating future scientists.



## **CHAPTER 5:SUMMARY, LIMITATIONS, CONCLUSIONS AND RECOMMENDATIONS**

### **5.1 Summary**

The main purpose of the study was to investigate whether the teaching of chemistry of water purification in Grade 11 using LAM through the SI approach would improve learners' understanding of the concepts of the topic. As discussed in Chapter 2, literature abounds in research reports that implicate chemistry as a difficult subject for many learners. The source of difficulties in chemistry arises from its conceptual and abstract nature. In order to evaluate the effects of SI instruction integrating LAM in a chemistry classroom, the quantitative component comprised mixed mode research within which a quasi-experimental design approach was followed. The qualitative component comprised a questionnaire and interview survey for learners that investigated their perceptions of the difficulty of chemistry of water purification.

The literature review section in Chapter 2 indicate that there is a gap in school laboratory-based inquiry because a variety of inquiry activities in the laboratory generally focus on the practical procedure that include handling of materials as opposed to understanding and investigation of concepts. However, there are LAM that could be integrated in the chemistry inquiry teaching process to close this gap and make understanding concept of water purification simpler.

The main findings of this study include the following:

1. As observed by Becker, et al. (1980), all groups improved in performance in post-test, RBT2, but experimental group scored relatively higher marks than control groups C and D, and the difference in means of marks of the two groups was significant in support of experimental groups A and B.
2. The instructional treatment designed and applied by the scholar to Grade 11 learners was perceived to be helpful in the study and that the learners more so, in the experimental group had acquired the needed investigative skills such as self-regulated and cooperative learning, critical thinking, doing a literature search and problem solving by performing the SI activities (i.e. practical activity 2: Building a simple water purification system) that integrated LAM.

3. The experimental group learners who were taught water purification through SI that integrated LAM performed on average better in RBT2 than those who were taught the same topic through a traditional approach.
4. Practical activity 2, which combined the use of LAM with SI instruction, produced better results than the routine teaching approach of chalk, and talk, discussions and problem solving.
5. Experimental group learners who experienced the SI instruction were more interested and intrinsically motivated than learners in the traditional instruction groups.
6. SI instruction that integrated LAM in this study contextualised learning of water purification and made the difficult descriptive chemistry concepts involved in this topic visible, simple and understandable.
7. If learners are given an authentic problem that is challenging and real, they will be more intrinsically motivated to learn and will enjoy the learning process immensely, especially when interacting with familiar materials.
8. The approach also increased problem solving and argumentative skills among learners through collaboration, as evidenced in the realisation of the water purification system and water purification devices designed for use at household level.
9. The magnitude of intervention was greater in the performance of the experimental group learners undergoing SI instruction, hence this approach was more effective than the conventional approach. The result of post-test RBT2 indicated that learners who were taught by the SI approach that integrated LAM were more successful than the learners who were taught using a conventional approach.
10. It can be concluded that SI that integrates LAM promotes the four types of scientific inquiry knowledge which are cognitive knowledge (subject content), representational knowledge (symbols/descriptive), presentational knowledge (writing skills ) and physical knowledge (laboratory hands-on skills) that are necessary to create future scientists who will provide cultural knowledge for the benefit of the wider scientific community. As observed by the National Research Council (2006), the learners who participated in this study did not learn the content of water purification and a few laboratory skills only; they were also taught to think and work like scientists.

## **5.2 Limitations of the study**

The small purposive sample of learner participants from only four schools limited the application of the findings to other high schools in the Vhembe District of Limpopo Province. This is because the small and purposive sampling strategy used in this study has provided rich descriptive information on the difficult nature of chemistry as part of the qualitative component; however, it does limit the transferability of the study to other contexts since it is not representative of other contexts (Patton, 2002). Therefore, the findings and conclusions from this small sample of participants should be applied for instructive rather than extensive purposes in science education.

An additional complex issue is that in group assessment, the workload is often not equally distributed. This inherent unfairness of group assessment in the RAT contributes significantly to learners' negative perceptions of group work. Many learners felt that the group size of approximately eight was too big for the learners to work together effectively. Learners had difficulty finding convenient times and places to collaborate on their presentations and felt that the workload was not equally distributed.

## **5.3 Conclusion**

From the findings of this study it can be concluded that the learners who were taught through SI integrating LAM performed better than those who were taught by the traditional approach. It is clear that LAM integrated in SI played a considerable role in the meaningful learning of chemistry of water purification by learners through reasoning skills, particularly during practical activities in the classroom.

## **5.4 Recommendations**

In the light of the findings,

SI instruction that uses LAM enhances learners' understanding, of theory, practice in laboratory and application of these theories and practices in the environment; the following recommendations are made:

1. One essential recommendation of this study is that chemistry teaching should create a constructivist or rich learning environment in which the learner is at the centre of the learning process and the teacher is at the centre of teaching the learner. SI instruction that integrates LAM, for example, provides learners with a situationally collaborative

environment in which they construct knowledge themselves with minimum guidance from the teacher.

2. Evidence from this study has shown that SI instruction that integrates LAM provides learners with opportunities to create their own meaning through solving authentic science problems that engage active learning. Therefore, the application and the utilisation of appropriate SI instruction is recommended to ensure learners' effective participation in the learning of chemistry.
3. Findings of the study, particularly regarding SI instruction integrating LAM, should be communicated to teachers and curriculum developers to improve practice in the classroom. Based on the results of the present study, that SI instruction that integrates LAM is an effective teaching approach, it is recommended that teachers undergo professional development to become more effective in their science teaching using the SI approach. The supply of science equipment must be accompanied by training on how to use this equipment, as well as modules on how to improvise or integrate LAM in the absence of or in cases of inadequate practical infrastructure when conducting science investigations at school.
4. Chemistry teachers should be encouraged to prepare teaching materials related to other topics guided by the conceptual model of SI instruction and the findings from this study. In this respect, the present study could be an important resource for chemistry teachers in South Africa and other developing countries.
5. Results of the study also suggest that chemistry textbooks should be revised to include the elements of conceptual change in science inquiry for different types of scientific knowledge and the integration of LAM. Textbooks and science equipment are necessary for effective science learning.
6. The SI instruction implemented in this study has the potential to promote the current call for Science and Technology in Society (STS) in school curricula, so that science carries real life meaning into the wider community.
7. In addition to the simple activities used in this study, using computer simulations based on activities could be suggested as a better teaching approach in the teaching of chemistry of water purification (Nakhleh & Monger, 1993).

8. Science teachers should sit practical examinations, and laboratory management courses should be part of teacher training programmes in order for them to appreciate the use of LAM and the value of scientific inquiry in classroom chemistry.
9. The results of this study revealed that most teachers are more concerned about their learners passing examinations, and they tend thus to ignore practical activities as they rush to finish the course and work on past examination questions. For this reason, learners should complete practical and research-based chemistry tasks and/or practical examination papers as they conduct investigations in the laboratory integrating LAM and processed materials as part of their final examination and their preparations for university studies. Practical examinations for learners should be made compulsory. This is particularly applicable to Grades 11 and 12.
10. As noted by the National Research Council (2006:133-134), this study required a great deal of time to conduct: four weeks for the implementation of the teaching plan comprising theory, laboratory activities, reflections after the laboratory activities, and four months for the completion of learners' innovative research project on water purification devices. This comprised carrying out the scientific method, report writing and group presentations. It is therefore suggested that research-based or context-based topics such as water purification be allowed ample time for teaching and learning in schools because of their integrative approach of theory, laboratory and application.
11. Based on reports from literature, which pointed out that integrative topics such as water purification do not have clear methodologies for implementation in most school curricula, it is recommended that the Department of Basic Education introduce elective or optional courses specialising in chemistry and physics application topics for Grades 11 and 12. These should comprise a significant proportion of the final examination. Chemistry and physics should not be combined as physical sciences, which currently offer surface knowledge, but be offered as in-depth specialised subjects for Grades 11 and 12. It is also recommended that Grade 13 be introduced in South African schools so that learners can specialise in advanced mathematics, physics, chemistry and biology, including integrative courses such as water purification, that offer broad and in-depth content, laboratory inquiry and integration of LAM in science pedagogy. It is also recommended that schools that will offer the proposed grade 13 should have, as a compulsory prerequisite fully

equipped laboratories that allow effective and meaningful science teaching and learning through scientific inquiry integrating LAM to take place.

12. Finally, it is recommended that teachers and examiners at all levels in the Department of Basic Education should set informal (internal) and formal (external) examinations particularly for learners in Grades 10 to 12, focusing on context-based chemistry in particular of research-based or environmentally-oriented topics such as water purification. Evidence from the study shows that such topics can be used as scenarios/cases in an integrated approach to link theory learnt in the classroom, practice in the laboratory and application in the environment. Such topics therefore have great potential to improve learners' performance, not only in chemistry but also in other related subjects such as biology (Simon, 1992).

### **5.5 Suggestions for Further Studies**

An extended study by way of replication of this study with larger samples may help to further understand and unpack the definitions of in-school laboratory science inquiry and the benefits of an SI teaching approach integrating LAM in the classroom. The definition of in-school inquiry is still suspect, because most learner experiments are confirmatory, merely replicating textbook results. Thus, a possible extension to this study could cover a diversity of schools with the purpose of investigating the effects of teaching an authentic topic in chemistry through SI instruction that integrates LAM. The focus should be on Education Design-Research (EDR) and Design and Technology (D&T) and the quantification of difficult aspects of the scientific method concerning learners' chemistry research integrating LAM. In addition, the benefits of group-based learning are widely recognised; however, there is still much that we need to learn to utilise this technique fully (Sampson, Cohen & Boud, 2001). It is clear that further research is needed to determine the value of this technique and to fully account for individual contributions to the whole when conducting chemistry research projects for learners.

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<sup>9</sup> The scholar submitted revised versions of this dissertation three times to Turnitin for Originality Check, and Appendix 15 shows a Digital Receipt in respect of the last submission.

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## 7.0 Appendices

### Appendix 1: Analysis of Questionnaires for learners

Questionnaire: Understanding chemistry of water purification

Please answer all the questions on the same question paper according to instructions that are provided.

*Please tick the appropriate box.*

#### 1. Performance in Paper 2 (Chemistry) examination in Grade 10

Below 30%	1
31%–79%	29
Above 80%	2

#### 2. Performance in research project of Paper 2 (Chemistry) in Grade 10

Fail: Below 30%	1
Pass: 30% and above	31

#### 3. Physical knowledge, experience or skills in the chemistry laboratory

Poor	24
Fair	6
Satisfactory	2
Good	0
Very good	0

#### 4. What do you consider most important when learning chemistry of water purification?

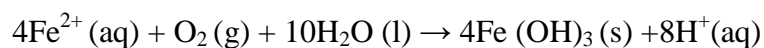
Notes on concepts	5
Tests	7
Practical activities	20

5. How could you describe your knowledge of the stages of water purification?

Poor	2
Fair	1
Satisfactory	7
Good	11
Very good	11

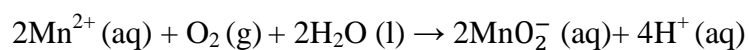
6.0 Assess your understanding of the following basic steps in the chemistry of water purification represented by the following ionic or chemical equations: 6.1–6.1.2?

6.1 Aeration through sand filtration precipitates metal ions as impurities in water:



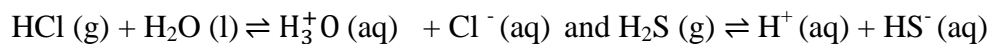
Poor	5
Fair	8
Satisfactory	6
Good	10
Very good	3

6.1.1



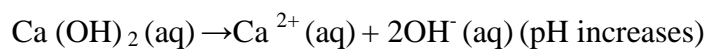
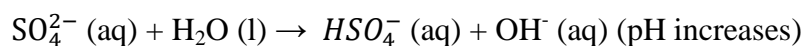
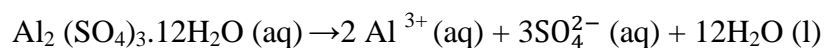
Poor	3
Fair	9
Satisfactory	4
Good	9
Very good	7

### 6.1.2 Trapping of gas in water:



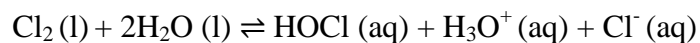
Poor	10
Fair	1
Satisfactory	7
Good	8
Very good	6

### 6.2 *Coagulation* by addition of alum and lime (electrolytes) causes the pH of water to increase and precipitation of small particles as impurities in water:



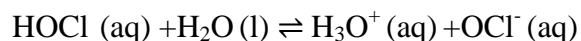
Poor	5
Fair	1
Satisfactory	9
Good	9
Very good	8

### 6.3 Chlorination:



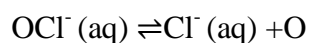
Poor	7
Fair	3
Satisfactory	6
Good	9
Very good	7

6.4



Poor	10
Fair	3
Satisfactory	3
Good	8
Very good	8

6.5



Poor	8
Fair	5
Satisfactory	2
Good	11
Very good	6

7.0 Briefly discuss how you would like the research topic chemistry of water purification to be taught. \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

8.0 Discuss the problems that you face when working with the chemical equations of the chemistry of water purification in the basic steps of aeration, coagulation and chlorination. \_\_\_\_\_

\_\_\_\_\_

9.0 From your point of view as a learner, suggest how best the chemical equations of water purification could be taught in the classroom setting? \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

THANK YOU.

*Analysis of open-ended questions for learners: 7.0–9.0*

Questions Learners	7.0 (Coded) <b>Suggestions: learning of the topic</b>	8.0 (Coded) <b>Problems</b>	9.0 (Coded) <b>Effective understanding</b>
1	2-Do some experiments	3 Balancing chemical equations	2 – Do some experiments
2	2 – In the laboratory by “doing”	2 – Coagulation (precipitation)	1 – Teach equations in detail
3	1-Teach using notes	3-Balancing chemical equations	1-Teach how to balance chemical equations
4	2 – Theory related to practical	0 – I don’t know	2 – By experiments
5	2-By doing practical	3-Balancing chemical equations	0-I don’t know
6	1 – Teach for understanding	3 – Balancing chemical equations	2 – Do some experiments
7	2 – .Carry out some investigation to clean water	2 – Coagulation (precipitation of ions)	1 – Teacher must use questioning approach
8	0 – I don’t know	3 – Balancing chemical equations	2 – Practical projects to remove impurities in water
9	2 – In the laboratory	3 – Balancing chemical equations	2 – Practical investigation
10	2 – “Able to do experiments to and see”	0 – Confusing	2 – By demonstration using chemicals
11	2-By practical investigations	3-Don’t understand equations	1-Pay attention in class

12	2-By some experiments	0-None	3-Teach chemical equations using different strategies
13	2-“By doing and observing results”	3-Balancing chemical equations	2-Practical investigations
14	2-By research	3-Balancing chemical equations	2-Teacher must demonstrate some experiments
15	2-By doing some practical tasks or activities	2-Process of removing chemical impurities	2-Use appropriate materials to demonstrate equations
16	2-By research to see how water is purified and get more marks	3-Formulae of compounds	1-Teacher must accommodate views of learners and give everyday examples
17	2-By experiment and practical investigation	3-Balancing chemical equations	1-Teach how to balance equations and stoichiometry
18	2-By research through literature searches	3-Don't understand chemical equations	0-I don't know
19	2-By demonstrations that dirty water can be purified	3-The practical tasks are confusing and not related to theory	3-Teach in class and demonstrate concept of water purification
20	1-Use teaching aids such as pamphlets	3-Balancing chemical equations	1-Questioning strategy of teacher: “Asking questions”
21	1-Teach by explanations and notes	3-Balancing chemical equations	1-Teacher must pay attention/ accommodate slow learners
22	2-By experiments	0-I don't know	2-By experiments

23	0-I don't know	0-Confused	0-None
24	0-Taught by theory in class related to practical	3-Balancing chemical equations	2-Teacher's explanations and demonstrations
25	2-Must supply apparatus and chemicals	2-Coagulation (precipitation)	1-Teach chemical equations particularly symbols and stoichiometry
26	0-Off the topic	0-Off the topic	1-Water purification a good thing to teach
27	2-By more research projects	1-Chlorination (how pathogens are killed)	1-Teach balancing equations
28	0-I don't know	0-I don't know	0-I don't know
29	2-Teacher must be resourceful; help organise locally available materials and some instruments for teaching	3-Balancing chemical equations	2-By using chemicals in laboratory; but there is a shortage
30	2-By lessons in class with related practical investigation	0-Lack of laboratory equipment to measure substances accurately	1-To understand better first teach word equations then chemical equations
31	2-Educational tours to municipal water purification plants (systems)	3-Balancing chemical equations	2-Teacher should use locally available materials and everyday examples
32	2-"By seeing or visiting local water plants and by experiments"	0-Poor background. Never been taught concept and no experiments	1-Patience with slow learners when teaching chemical equations

*N.B: Codes 0, 1, 2, and 3 used above represent responses which are similar.*

Open Question 7.0

Teaching and learning approach	Code	Frequency of codes	Per cent
Practical tasks (experiments, research projects, educational tours)	2	24	75.0
Theory: classroom lessons using traditional methods	1	4	12.5
No knowledge or response	0	4	12.5
Total	2	32	100

Open Question 8

Problems	Code	Frequency of codes	Per cent
Coagulation/precipitation	3	4	12.5
Chemical equations	2	18	56.3
Chlorination	1	1	3.1
No knowledge or response	0	9	28.1
Total	3	32	100



Open question 9

<b>Effective understanding</b>	<b>Code</b>	<b>Frequency of codes</b>	<b>Per cent %</b>
Theory and practice	3	13	40.6
Practical investigations (experiments, research and tours)	2	13	40.6
Theory: classroom lessons	1	2	6.3
No knowledge or response	0	4	12.5
Total	3	32	100

## **Appendix 2: Interview questions and transcripts for learners**

- Welcomes and Inductions
  - Rational of the interview: learners were assured that their identities would be concealed. Anticipated impact of the of the findings an recommendations of the dissertation regarding contribution to science education in Vhembe District and beyond
- 1 What do you think the term water purification means?
  - 2 Think about ways in which a water source becomes contaminated or polluted. What do you think are the causes of water contamination?
  - 3 Briefly describe how solid particles are removed from waste water during water purification or treatment of water.
  - 4 Briefly discuss how chemical impurities are removed from waste water during water treatment.
  - 5 Which household chemical can you use to disinfect water by killing pathogenic organisms such as bacteria? Use your knowledge of the periodic table to support why this chemical is an effective disinfectant.
  - 6 Sand and carbon filtration and chlorination are the main stages of water purification. Which of the stages do you consider to be difficult for you to learn? Please suggest a reason for your answer.
  - 7 Suggest how best you could learn the chemistry of water purification in the classroom?
  - 8 Do you consider the chemistry of water purification to be difficult?
  - 9 Please comment on your performance in the chemistry research project in Grade 10.
  - 10 What problems have you faced when learning chemistry of water purification or other related projects at school?
  - 11 What are your feelings about this interview on the topic water purification?

**Table 1: Summary of transcripts from learner interviews**

Interviews elicited the learners' views and difficulties in learning the chemistry of water purification and were transcribed verbatim. A response for each question is coded with numbers 0,1,2,3 or 4.

Question	Learner 1	Learner 2	Learner 3	Learner 4	Learner 5	Learner 6	Learner 7	Learner 8	Learner 9	Learner 10
1	1-Removal of germs, bacteria	1-Removal of undesirable thing	1-Cleaning of water	1-Cleaning dirty water	1-Cleaning by recycling	0-Polluted by dirty things	1-Cleaning water for drinking	1-Cleaning of water	1-Water is purified for drinking	1-Cleaning for drinking
2	1-Rubbish	1-Chemicals	1-Organic matter	1-Waste materials	1-Chemicals and biological impurities	1-Activities of people and animals	1-Chemicals and litter	1-Littering	1-Chemical, biological and physical impurities	1-By human activities
3	0-Use machines and chemicals	0-Easy to remove, solids do not melt;	0-Carbon filter	1-Soil filtration	0-By municipal water treatment plant	1-By sand filtration	1-By Sand filtration	0-Use distillation	0-No answer	1-Sand filtration

4	0-Use Jik or boil water	0-Use Jik	0-Kills microbes in water	0-Use chemicals	0-By chlorination	1-By carbon filtration	1-By carbon filtration	0-By chlorination	1-By carbon filtration	1-By carbon filtration
5	0-Chlorination	1-Jik	1-Jik	1-Jik or bleach	0-Chlorination	1-Jik or boil water	1-Bleach	1-Jik	1-Bleach or boil water	0-Chlorination
6	2-Chlorination	2-Chlorination	2-Chlorination	0-None	1-Carbon filtration	2-Chlorination	1-Carbon filtration	2-Chlorination	2-Chlorination	0-None
7	0-Know water reticulation	1-Teacher notes	0-Know all processes	2-By Practical investigation	3-By theory and related practical investigation	1-By Notes	3-By Experiments and practical investigation	2-By appropriate apparatus and chemicals	2-By notes and experiments	2-Practical investigations
8	1-Yes	0-No	1-Yes	0-No	0-No	0-No	0-No	0-No	1-Yes	0-No
9	4-Very good	3-Good	0-Absolutely bad	1-Fair	1-Fair	0-Never done any projec	1-Good, but not satisfi	2-Satisfactory	1-Fair	3-Good

						t	ed			
10	1-Not unders tandin g equati ons	1- Short time to finish	1-Did not under stand proces ses	1- Teach er unable to teach	1- Carbo n filtrati on is difficu lt	0- None	0-No labora tory	0- None	1- Proble m of unders tandin g concep ts	0- None
11	3- Good	3- Good, proud	0- None	3- Good	4- Very good	3- Good	3- Happy	3- Good	3- Good	3- Good

*Analysis of transcripts from learner interviews;*

*Code 1=correct, Code 0= incorrect*

Question	Code	Frequency
1.Term water purification	0	1
	1	9
2.Causes of impurities in water	0	0
	1	10
3.Removal of solid impurities	0	6
	1	4
4.Removal of chemical impurities	0	6
	1	4
5.Household disinfectant	0	3
	1	7

6. Difficult stages of water purification

Level of difficulty	Code	Frequency
Don't know	0	2
Difficult: carbon filtration	1	2
Very difficult: chlorination	2	6
Total	2	10

7. Effective learning approach

Learning approach	Code	Frequency
No knowledge	0	2
Theory: classroom lessons	1	2
Practical tasks	2	4
Theory related to practice (minds-on, hands-on)	3	2
Totals	3	10

8. Chemistry of water purification

Difficulty(Yes /No)	Code	Frequency
No	0	7
Yes	1	3
Totals	1	10

9. Performance in chemistry research projects in grade 10

Rating	Code	Frequency
Poor	0	2
Fair	1	4
Satisfactory	2	1
Good	3	2
Very good	4	1

10. Problems in learning chemistry of water purification at school

Problems	Code	Frequency
Did not understand	0	3
Partial understanding	1	6
Understood well	2	1
Total	2	10

11. Feelings about interview

Rating	Code	Frequency
Poor	0	1
Fair	1	0
Satisfactory	2	0
Good	3	8
Very good	4	1



### Appendix 3: Research Based Test 1 (RBT1) and suggested answers

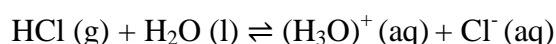
#### QUESTION 1

1. Which statement best explains why water exists as a liquid at standard temperature and pressure?
  - A. Due to hydrogen bonding between water molecules ✓✓
  - B. Due to covalent bond between hydrogen and oxygen atoms in water molecule
  - C. Due to polarity of water molecule
  - D. Due to polar covalent bond in water molecule
2. “Pure” water is a poor conductor of electricity, but “hard” water is a good conductor because it contains mainly which metal ions?
  - A.  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$
  - B. Hg and Pb
  - C. Cd and Ni
  - D.  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  ✓✓
3. Which of the following chemicals is a common household disinfectant that can be used to disinfect water?
  - A. Chlorine gas
  - B. Bleach (Calcium hypochlorite) ✓✓
  - C. Chloramine
4. The pH of water is defined as
  - A. Amount of  $\text{H}^+$  ions in water ✓✓
  - B. Amount of  $\text{H}^+$  and  $\text{OH}^-$  in water
  - C. Amount of  $\text{OH}^-$  in water
  - D. None of the above
5. A filter medium must have constant composition and uniformity such as silica. Which one of the following physico-chemical properties is not characteristic of an effective filter medium?
  - A. Hard
  - B. Insoluble in water
  - C. Neutral pH
  - D. Soluble in water ✓✓

6. Silica is the most common filter medium. Use your knowledge of the chemistry of silica to deduce which one of the following locally available materials is not suitable to use as a filter medium.

- A. Crushed glass filings
- B. Mineral ash or charred vegetation✓✓
- C. Sand, silt and gravel
- D. Mineral tilings

7. Deduce how water is behaving in the reaction represented below during aeration in the dissolution of HCl:



- A. Weak acid
- B. Both acid and weak base
- C. Weak base✓✓
- D. Strong base

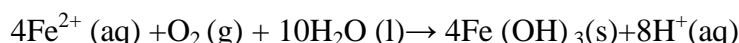
8. Which of the following descriptions is true of the activated carbon or charred vegetation during the process of water purification?

- A. A physical change that involves filtration of solid impurities
- B. Biological purification by process of chlorination to kill pathogens
- C. Chemical process that involves adsorption of metal ions as impurities✓✓
- D. Combination of chemical, physical and biological processes of removing impurities

9. Study the reaction of the chlorination of water:  $\text{OCl}^- (\text{aq}) \rightarrow \text{Cl}^- (\text{aq}) + \text{O} (\text{aq})$  and conclude what the O formed is:

- A. Oxygen atom✓✓
- B. Oxygen ion
- C. Oxygen molecule
- D. None of the above

10. The following chemical equation involves the aeration of water containing  $\text{Fe}^{2+}$  ions as impurities.



Which one of the following statements is correct?

- A.  $\text{Fe}^{2+}$  is reduced
- B.  $\text{Fe}^{2+}$  is oxidised✓✓

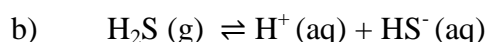
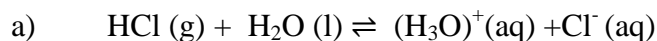
C.  $\text{H}^+$  is oxidised

D.  $\text{Fe}^{2+}$  does not change oxidation number

[20]

## QUESTION 2

2. Aeration of water allows impure gases trapped in the water to escape according to the following equations:



- 2.1 Equation a) represents an acid-base system.

- 2.1.1 Which molecule in equation a) is acting as an acid? Explain your answer in terms of the Bronsted-Lowrey theory of acids and bases. (4)

*HCl. Proton donor*

- 2.2 Are the chemical reactions represented by a) and b) **REVERSIBLE** or **IRREVERSIBLE**? Explain your answer. (4)

*REVERSIBLE. Because direction of reaction depends on concentrations of reactants and products, levels of oxygen and also on temperature.*

- 2.3 Do  $\text{HCl}_{(\text{g})}$  and  $\text{H}_2\text{S}_{(\text{g})}$  dissolve in water as impure gases? (1)

*Yes.*

- 2.4 Use equations a) and b) to explain the terms hydration and hydrolysis. (4)

*Addition of water (hydration) to HCl and  $\text{H}_2\text{S}$ , which are ionic gases takes place first, followed by hydrolysis when gases dissolve or dissociate into their ions due to dissociation of water*

- 2.4.1 Explain or suggest how the two gases are removed from water during water purification process. (4)

*Since these reactions are reversible, the reverse reaction is favoured when oxygen is added to water (aeration), dehydration increases (less available water) resulting in the release of impure gases HCl and  $\text{H}_2\text{S}$ .*

[17]

## QUESTION 3

3. Silica in group 14 of the periodic table is the most common filter medium used. Silica has characteristics of constant composition and uniformity.

- 3.1 Explain what is meant by a physical change. Then deduce whether filtration is a physical, chemical or biological change. (3)

*No new substance is formed; substance has no constant composition, easily separated with little or no energy involved and process easily reversible. Physical change.*

- 3.2 Give the chemical formula for silica or silicon (iv) oxide.

$\text{SiO}_2$  (2)

- 3.3 Identify any two locally available materials and explain how they could be used as filter media in water purification systems.

(4)

*Crushed glass, sand, silt and gravel or mineral pieces (any other appropriate filter medium)*

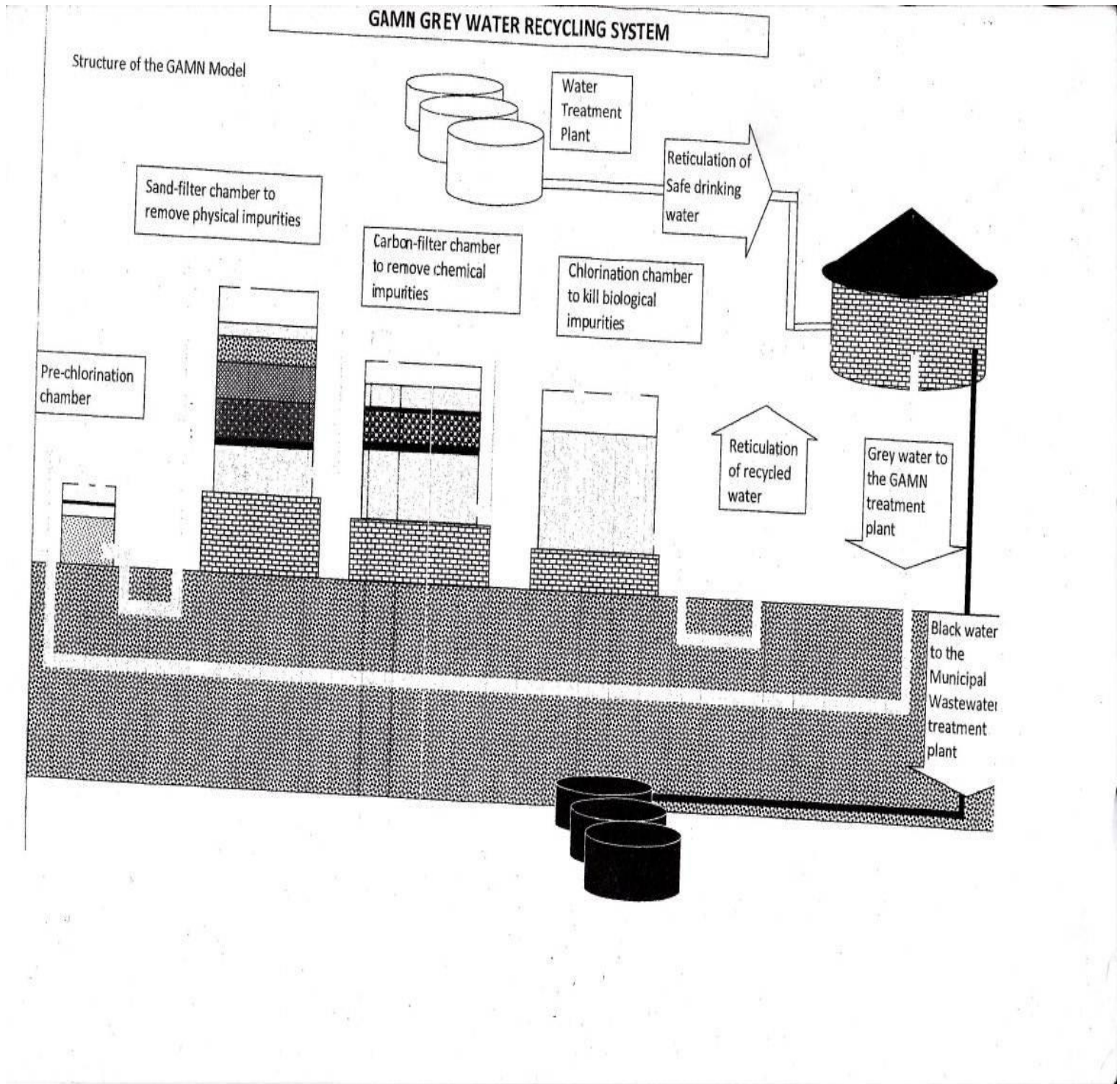
- 3.4 Use knowledge of solubility of water to argue why the identified locally available materials possess the ideal physico-chemical properties to make alternative filter media. (4)

*Water being a polar covalent molecule with dipole moments ( $\text{O}^{\delta-}$  and  $\text{H}^{\delta+}$ ) is a polar solvent therefore a practical filter medium should be hard, insoluble in water and with neutral pH, constant in composition and uniform.*

[13]

**Grand total: 50 marks**

#### Appendix 4: Model diagram of water purification (recycling) at household level<sup>10</sup>



<sup>10</sup> The model diagram is a simplified demonstration of stages of water purification, and it became very useful in lesson 1, and applicable in water purification experiment and project done by the learners. Adapted from DWAF, (2010)

## Appendix 5: Lesson 1 (Chemistry of water purification integrating LAM)

Subject: Grade 11 Physical Sciences: Experimental groups (A and B)

Duration: Two class periods (2 x 45 minutes) x 2

Topic: Aquatic chemistry and chemistry of water purification (2x 45 minute double lessons) and enrichment activity 1 (2x45 minutes afternoon study time)

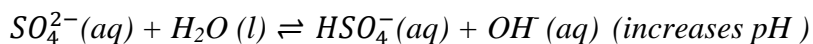
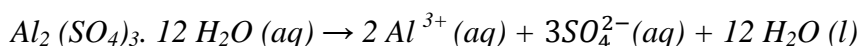
### Lesson objectives

- i. Learners should be able to distinguish and explain physical, chemical and biological impurities in water which cause water to become contaminated
- ii. Learners should be able to explain the relationship between chemistry of water purification, impurities in water and LAM that can be used to purify water.
- iii. Learners should be able to explain the meaning of *water purification* using the five basic chemistry concepts to water purification: aeration, coagulation, sedimentation, filtration, and disinfection by chlorination.

Learning Outcomes	LO1-Scientific enquiry and problem-solving skills. Learners construct knowledge on the topic.	X	Assessment standards (AS) AS 3 and AS 4
	LO2-Constructing and applying scientific knowledge. Learners should interpret the topic and relate it to water impurities and LAM to purify water.	X	AS 1 and AS 3
	LO 3-The nature of science and its relationship to technology, society and the environment. Learners in groups discuss how concepts of environmental chemistry of water purification can be applied to save water.	X	AS 1 and AS 3

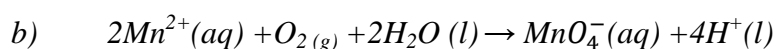
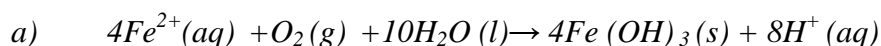
Prior Knowledge	<ul style="list-style-type: none"> <li>– Physical chemical properties of water</li> <li>– Molecular structure of water (co-ordination chemistry)</li> <li>– Water as a solvent: polar covalent molecule with dipole moments</li> <li>– Uniqueness of hydrogen bonding in life systems</li> <li>– Acid-base systems in aqueous solutions (Brønsted-Lowry Theory) and pH of water</li> <li>– Redox reactions and precipitations of metal ions as impurities in water</li> </ul>					
Integration subjects	Languages	Life Sciences	History	Geography	Commerce	Life Orientation
		x		X		x
Context	<ul style="list-style-type: none"> <li>– Purifying water by physical, chemical and biological processes</li> <li>– Definition of water purification</li> <li>– Identification and categorisations of different types of water impurities</li> </ul>					
Content	<p><b>Water impurities</b></p> <p><i>Physical impurities:</i> solids, e.g. small dead plants and animals, colloidal matter such as humus, segments such as clay, sand, gravel and silt that are removed by sand filtration (see Appendix 4).</p> <p><i>Chemical impurities:</i> inorganic salts, organic compounds, mineral acids, heavy toxic metals, metal compounds and organometallic compounds.</p> <ul style="list-style-type: none"> <li>– Soluble toxic materials such as <math>\text{Cu}^{2+}</math> and <math>\text{Zn}^{2+}</math> ions are removed through adsorption by activated carbon filter (see Appendix 4).</li> <li>– Toxic heavy metals such as Cd (s), Hg (s), and Pb (s) are also present in polluted waters near industry effluent.</li> <li>– <math>\text{Fe}^{2+}</math> and <math>\text{Mn}^{2+}</math> impurities precipitate out of water in higher oxidation states during <i>coagulation</i>.</li> <li>– <math>\text{H}_2\text{S}</math> (g), HCl (g), <math>\text{NH}_3</math> (g) and volatile organic compounds dissolve in water and hydrolyses during <i>aeration</i>, and dehydration releases these impure gases in reverse direction.</li> <li>– <i>Biological impurities:</i> small plants and animals, bacteria, viruses, fungi and algae.</li> </ul> <p><i>Chlorination</i> disinfects water by killing pathogenic organisms.</p> <p>Representing chemical reactions in three water purifications steps:</p> <p><i>Coagulation (sedimentation):</i> results in the addition of alum and lime (electrolytes) to</p>					

dirty water and increases pH to slightly basic which causes metal ions to precipitate, bringing the small particulates with them and the water becomes clear.



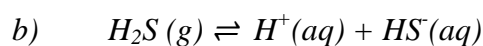
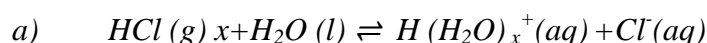
*-Aeration:*

The equations below represent a redox system involving aeration of water, which results in the removal of some metal ions as impurities.



Explain redox in terms of change of oxidation numbers of  $Fe^{+2}$  and  $Mn^{+2}$  that precipitate out of water in higher oxidation states.

*Aeration* of water allows impure gases trapped in the water to escape according to the following equations (hydration followed by hydrolysis):



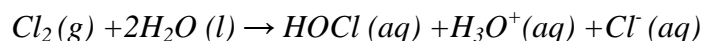
Explain the chemical behaviour of the impure gases in terms of the Bronsted-Lowrey theory of acids and bases and identify acid-base conjugate pairs.

*Chemistry of chlorination (disinfection)*

Chlorine in group 17 of halogens is a very reactive, strong oxidising agent and effective disinfectant. Chlorine kills pathogens by replacing one or more of the hydrogen atoms in the molecule, causing the entire molecule to disintegrate.

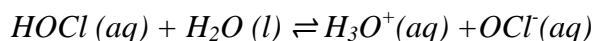
When chlorine gas is added to water hypochlorous, a weak acid and hydrochloric acid form:

*Chlorine + Water  $\rightarrow$  Hypochlorous Acid + Hydrochloric Acid*



Depending on the pH value, hypochlorous acid partially dissociates to hypochlorite and hydronium ion:

*Hypochlorous Acid  $\leftrightarrow$  Hydronium Ion + Hypochlorite Ion:*



The reaction is reversible. Disinfection is more efficient at a low pH (with large



	<p>quantities of hypochlorous acid in the water) than at a high pH (with large quantities of hypochlorite ions in the water.)</p> <p>This dissociates to chlorine and oxygen atoms:</p> $OCl^{-}(aq) \rightleftharpoons Cl^{-}(aq) + O^{-}(aq)$ <p>Hypochlorous acid (HOCl, which is electrically neutral) and hypochlorite ions (<math>OCl^{-}</math>, electrically negative) will form free chlorine when bound together. This results in disinfection.</p> <p><i>Hypochlorite (Bleach)</i></p> <p>Bleaches (hypochlorites) are less pure than chlorine gas. The reactions of bleaches sodium hypochlorite and calcium hypochlorite with water are shown below:</p> <p><i>Calcium hypochlorite + Water → Hypochlorous Acid + Calcium Hydroxide:</i></p> $Ca(OCl)_2(aq) + 2 H_2O(l) \rightarrow 2 HOCl(aq) + Ca(OH)_2(aq)$ <p><i>Sodium hypochlorite + Water → Hypochlorous Acid + Sodium Hydroxide:</i></p> $NaOCl(aq) + H_2O(l) \rightarrow HOCl(aq) + NaOH(aq)$ <p>Hypochlorous acid, which is neutral, can penetrate negatively charged slime layers, cell walls and protective layers of pathogens and kill them more effectively than negatively charged hypochlorite ions, which result in repulsions.</p>				
Skills	Communication during in-class discussions of the chemical equations of water purification				
Knowledge	Knowledge of redox systems, acid-base system and precipitations represented in chemical equations				
Values	Work together in groups; listen to others' views and cooperate.				
Teaching strategy/methodology	Question and answer	X	Investigation	X	
	Explanation	X	Observation		
	Discussion	x	Others		
Activities					
Learners		Teachers			
– Draw mind maps of water purification at home. – Discuss in groups the meaning of water purification.		In-class discussions using question and answer approach: – Notes and discussions on the causes of water impurities. – Explanation of the chemistry occurring at each stage of water purification using chalk and talk approach, mind			

<ul style="list-style-type: none"> <li>– Identify water impurities and group them as physical, chemical or biological water contaminants.</li> <li>– Discuss why the physical and chemical properties of sand filter, activated carbon filter and chlorine are appropriate for purifying water (see Appendix 4).</li> <li>– Able to discuss in groups the chemical equations that are basic to water purification: coagulation (precipitation), aeration and chlorination.</li> </ul>		<p>maps and model diagrams of water purification (see Appendix 4).</p> <ul style="list-style-type: none"> <li>– Explanations of the chemical equations of coagulation (precipitation), aeration (hydration and hydrolysis) and disinfection by chlorination.</li> </ul>					
<p>Evidence of achievement:</p> <ul style="list-style-type: none"> <li>– Able to identify the three major purification stages on model diagram of water purification (see Appendix 4)</li> <li>– Able to name, with chemical reasons, the materials needed to purify water.</li> <li>– Able to write and explain during question and answer sessions the chemistry occurring during water purification steps of aeration of water, coagulation or precipitation of metal ion impurities and killing of pathogens by chlorination.</li> </ul>		Assessment					
		Forms		Tools		Method	
		Test/Exam	x	Memorandum	X	Teacher	X
		C/H Work		Checklist		Self	
		Project		Rubric		Peer	
		Investigation		Observation sheet	X	Group	X
		Assignment					
		Other: specify group work		Other: Specify		Other: Specify	
Resources:		Expanded opportunities					
<p>Worksheets, writing materials, models, textbooks, sand and silt of varying textures, charred vegetation/bones, bleach powder, dirty</p>		Remedial			Enrichment		
		<ul style="list-style-type: none"> <li>– Assign class discussion for the next session of 45 minutes on the relationship between chemistry of water purification, water contaminants and locally available materials to purify water to motivate</li> </ul>			<ul style="list-style-type: none"> <li>– Give learners extra questions to answer at home using “need to know” worksheet on:</li> <li>– their ideas and how and what they want to know about chemistry of water purification using locally available</li> </ul>		

water, litmus paper, empty plastic bottles, dirty water, model diagram of water purification (Appendix 4), innovative research project task (Appendix 6)	learners and increase their conceptual understanding. After enrichment class discussions guided by the researcher learners write activity 1 with support model diagram of water purification (Appendix 4).	<p>materials.</p> <ul style="list-style-type: none"> <li>– the design of a prototype water purification device using a schematic diagram with appropriate locally available materials.</li> <li>– Learners write an extension activity1 (Appendix 5.1).</li> <li>– Learners given an innovative research project task on the innovative research project at the end of the lesson (see Appendix 6).</li> </ul>
<p>Reflection: the planned work was well done; learners were able to integrate previous lessons on water chemistry of water purification chemistry (application chemistry), and drew mind maps/designs representing the three major purification stages of water. Learners were motivated as materials needed for the water purification stages were readily available and familiar. Learners were keen to move on to the next stage of making a prototype water purification device at household level using LAM.</p>		

### **Appendix 5.1: Enrichment Activity 1 (Water purification, water impurities and LAM)**

*Learners were allowed to use the model diagram of water purification (recycling) in Appendix 4 to complete this activity.*

1. What do you know about water purification? (2)
2. How can you be sure that a sample of used water from your bathroom or sink contains impurities? (3)
3. Categorise the impurities that you think are found in grey water as physical, chemical or biological impurities. (2x3)
4. Use your knowledge of aquatic chemistry to explain the chemistry (with chemical equations where possible) occurring at the following major stages of water purification (see Appendix 4):
  - a) Sand filtration
  - b) Carbon filtration
  - c) Chlorination (3x4)
5. Discuss the physical and chemical properties of locally available materials that are most appropriate for purifying water at each of the above stages. (3x4)
6. Draw a schematic diagram or concept map illustrating the stages of water purification using LAM in the design of a prototype water purification device. (10)

**Grand total: 45**

## **Appendix 6: Innovative research project task (the Scientific Inquiry Process) <sup>11</sup>**

Learners will be given the innovative research project task as part of the enrichment or extension of activities (see lessons 1, 2 and 3) to enhance their understanding of the theory of the chemistry of water purification using LAM. Learners will carry out an innovative research project by applying classroom chemistry to water purification using LAM.

The project focus will be on the chemical concepts of aeration – the role of oxygen in water treatment, coagulation as a chemical tool to clarify water, sedimentation and filtration as physical tools to clarify water and chlorination to disinfect pathogens in filtered water. Learners will read the scenario of water shortages in South Africa and derive a problem statement that will guide them in using the chemistry of water purification to make a prototype water purification device following SI, as detailed in the innovative research project task.

### **The Scenario (Water Shortages in South Africa)**

South Africa is generally a dry country with some areas such as the Limpopo Province experiencing periodic droughts, often approaching crisis point where there is not enough water for human consumption. It is therefore suggested that purification of water, starting first at household level but moving to water source reuse of borehole or municipal water will save water for South Africa.

**The task:** This is an innovative type of research project.

**Title:** How to apply chemistry of water purification in the design and development of a water purification device at household level, using locally available materials *You may rephrase the title but keep the key words.*

**Time line:** Four months.

In your research, identify and describe the problem of looming shortages of fresh drinking water in South Africa. Then create opportunities to demonstrate that you are able to address the problem by collecting relevant data from different sources of your choice, such as

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<sup>11</sup> The learners' innovative task that used LAM complemented the definition of scientific inquiry instruction, in particular the procedure. SI was characterised, as learners' project task that comprised application of chemistry including LAM to solve issues of water clarification. The SI process was adapted from DWAF (2010) and University of Cape Town (2010).

textbooks, newspaper articles, magazine articles, the internet, chemistry lessons, materials in the local environment etc. for the purpose of building the water purification device at household level. Your findings should then be presented in the form of a proposal, which should be written following the guidelines below:

### **The Scientific Inquiry (SI) Report format:**

1. **Acknowledgements:** Mention any type of **special help** you received from a **named** individual, group, or institution. This section is to say *'Thank you'*.
2. **Abstract:** This is a brief summary of the research project, i.e. essential features of the research. Use **no more than 200 words**. No references. The novel features of the prototype device involve construction, arrangement and the combination of parts to assemble the device. In your summary, you should attempt to answer the following questions related to water purification :
  1. How does the water purification system operate?
  2. How do you collect the grey water to be purified ?
  3. Who will use your present water purification device?
  4. Which suitable materials and tools did you gather to assemble the device?
  5. Which appropriate construction methods did you use to design and develop the device?
  6. What is the appearance of your present device? Is it user-friendly, affordable, portable, etc.? Refer to its size, shape, colour, etc.
3. **Table of contents:** Outline of chapters, headings and corresponding pages in table form just like the “Table of contents” found on the first few pages of most textbooks.
4. **Research title:** Be specific. The title is derived from the intended focus of your study. In this research, the title is derived from the task and introduction stated above.
5. **Introduction or Background to invention:** Use 500 words or less. Say something relevant about:
  - What is the problem? How does it arise? What are the effects of this problem?

- The structure of the report and a brief summary of each part.
- Key words: *e.g. water scarcity; water rationing; periodic drought area; waste water; grey water; water conservation; water purification device; water reuse; saving water; water treatments; types of filtration; chlorination; locally available materials.*

6. **Identification of the problem:** The problem is normally stated as a question:

7. **Purpose:** What benefit or goal is to be gained from a better understanding of this question or the making of the water purification device?

8. **Significance of the problem:** Comment on why this problem/hypothesis merits investigation.

9. **Research Questions:** Design set questions, which will need to be answered in order to solve the problem identified and to address the variables. There may be more than one question.

10. **Assumptions:** Explain everything that is assumed in order for the design and development of the device to be undertaken.

11. **Limitations:** Explain the limitations/shortcomings that may invalidate the invention of the device or make it less than accurate in terms of operation.

12. **Project focus/Literature review:** Write one or two paragraphs on:

- What does the project touch on?
- What are you focusing on?
- What views exist on water purification?
- What has been said about this problem, i.e. for or against the subject matter?
- Interpret basic chemistry concepts of water purification supported with chemical equations where possible to show what happens at each stage. Learners should explain how the chemistry of aeration, sedimentation, coagulation, filtration and chlorination purify water and make it safe enough for environmental use or drinking.

**13. Key terms:** List at least eight key terms or concepts used in the study.

**14. Identify the variables in your research:** The design of the prototype device depends on the availability of locally available materials and/or tools and chemistry knowledge of the topic that is used to design a device with the appropriate measurements (areas, volumes, etc.) according to scale within a specified time frame of four weeks. Identify independent and dependent controlled variables. These are the things you would gather data about to prove your hypothesis.

**15. State the Hypothesis:** Statements that attempt to answer the questions above. It is an educated guess that answers the problem in the study and this should be written in terms of variables.

**16. Project design:** Use mind maps, schematic views, symbols, flow charts, sketches, technical drawings, models, etc. to illustrate the design of the proposed water purification device you intend to make. (Drawings of the proposed water purification device may not be to scale.)

- Model of proposed device: draw a schematic model showing the stages of water purification and explain the chemistry occurring at each stage.
- Drawing of design: draw a design of proposed device to the appropriate or approximate (rough) scale.

**17. Materials used:** List the bank of materials, i.e. tools, locally available materials, chemicals, etc. used to make the water purification device. Tools will be needed for marking out, cutting and mouldings.

**18. Procedure/Method:** Write down in detail or in point form the method you used to collect materials, to design and develop/make the prototype water purification device. Explain step-by-step what was done. Give information as to what, when, where and how data for making the device were collected and by whom. How did you make the device? In this section, write down the appropriate construction method used in point form, accompanied by a schematic or flow chart diagram of the device.



- 19. Results:** Data collected may be expressed in the form of tables, graphs or pie charts. Drawings/diagrams/photographs of the prototype device should be clearly labelled showing space, symbols, arrows, etc.
- 20. Discussion and conclusion:** Briefly describe, in terms of scientific and technical processes, how the prototype water purification device purifies and saves water. The research question is answered, the hypothesis stated and the decision to accept or reject the hypothesis is made.
- 21. Recommendations for further research:** From the knowledge/experience gained from this research, how could the study be improved or what other problem/hypothesis might be investigated?
- 22. References:** A list of resources which were used in your research report.

## **Appendix 7: Lesson 2 (Building a simple water purification system using LAM)**

Subject: Grade 11 Physical Sciences

Duration: Two class periods (90 minutes)

Topic: Activities on chemistry of water purification

Worksheet used in the chemistry of Water Purification: Building a water purification system

### **Purpose of lesson**

The aim of the following activity is to teach the difficult aspects of the chemistry of water purification effectively, using LAM to enhance learners' understanding of the chemistry occurring at each stage of the process as mentioned below:

- a) Aeration and filtration of solid impurities in water using locally available materials such as sand, silt and gravel, crushed glass, mineral tailings and bottom ash
- b) Coagulation resulting in precipitations of colloids in water using electrolytes such as aluminium sulphate (alum) and calcium hydroxide(lime) and
- c) Disinfection of water by chlorination using household solid bleach calcium hypochlorite or liquid bleach sodium hypochlorite.

### **Lesson objectives**

Learners should be able to:

- a) relate chemistry of water purification with water impurities and LAM that remove the impurities
- b) use chemical equations to explain purification steps of aeration, coagulation (precipitations) and chlorination
- c) determine the amount of bleach needed in the laboratory chlorination of filtered water for purposes of environmental or drinking use.

### **Pre-Activity assessment**

Ask the learners to present what they wrote on their ideas and questions about water purification in their “need to know” worksheets, and on how chemistry of water purification can be translated into the prototype of a water purification device using LAM. Learners are to

present and discuss in class the schematic design of this prototype using new knowledge gained in lesson 1.

### **Activity Assessment**

Learners will be given activity sheets that guide them on how to build a simple water purification system. Learners will answer questions and draw diagrams on the spaces provided on the question paper. The inquiry type questions required learners to apply concept-laboratory practice-application in the environment of the basic chemistry of water purification, particularly to draw a well labelled diagram that illustrates chemical reactions occurring at each stage of the process. Learners will use a practical approach of predict, observe and explain chemical reactions that clarify water at each stage of the process.

### **Post-Activity assessment**

Summative assessment:

- The researcher will mark and analyse all answered activity sheets.

Formative assessment:

Researcher will observe learners behavioural changes through verbal communication that include in-class discussions through question and answer sessions, and non-verbal communication modes such as their body actions, facial reactions to teacher' comments, etc

### **Activity extensions**

- Learners to apply chemistry of water purification in an innovative research project on the design and construction of a prototype of a water purification device using LAM (see Appendix 6).

### **Apparatus and chemicals needed to carry out activity (LAM included):<sup>12</sup>**

- 3 litres of grey or muddy water from a nearby stagnant pool (LAM)
- 5 litres of clean water (LAM)
- 2-litre cooking oil bottle with a lid (LAM)

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<sup>12</sup>The procedure, in particular materials for water purification experiment using locally available materials was adapted from Home Science Tools: Water Purification Science Project available at [ <http://www.hometrainingtools.com/a/water-filtration-science-project/> ], and Water Experiments of The Global Experiment of the IYC (2011 ) available at [ <http://water.chemistry2011.org/web/iyc> ]

- 2-litre plastic cooking oil bottles, one with its bottom removed to use as funnel and the other with its top removed to use for sedimentation a filter bottle filled with layered sand, sand silt and gravel filter media (LAM).
- two wide opened cooking oil drink bottles or large beaker with a volume of 1000 ml (LAM) for collecting filtered water
- 10 g alum (aluminium sulphate)
- Universal indicator or litmus paper to test pH of water
- 700 g fine sand (LAM)
- 700 g silt sand (LAM)
- 500 g gravel (LAM)
- one tea filter or translucent cotton cloth (LAM)
- one elastic band (LAM)
- one large spoon for lifting and mixing alum and water (LAM)
- A wrist watch clock or clock with a second hand (LAM)
- 2 g household disinfectant bleach powder 2 ml of or liquid bleach (calcium hypochlorite) (LAM) to disinfect one litre of filtered water
- marsh water bottle for collection of dirty water from muddy pool or kitchen sink.

**Procedure to do the activity:**

The researcher assists the learner to carry out the demonstration. The researcher to draw a mind map or concept map of the Water Purification System on the board, assisted by other learners in an in-class discussion. Using question and answer technique the researcher asks learners after a mind map is constructed on the chalkboard to describe and explain what happens at each stage of the water purification process in their illustration.

*WARNING: Researcher cautions learners to be very careful when using cutting items like blades, and chemicals such as alum and bleach because they are not only very toxic, but can*

*be even lethal if ingested and can cause skin damage. Learners were also encouraged to put on their laboratory protective clothes for their safety.*

1. Pour muddy or grey water into the 2-litre bottle that has a cap. Observe how the grey water looks and smells. Record all your observations in your “need to know worksheet”
2. Put the cap on the bottle and shake vigorously for 40 seconds. Then pour the water back and forth.
3. Pour the water into top part of the cut off bottle. Observe and record appearance and smell of the water. Test the water for pH using universal indicator or litmus paper.
4. Add about 5 g of alum to the water in the bottom part of the top cut off filter bottle. Gently mix the water with spoon for eight minutes. What do you see happening to the water as you mix it?
5. Allow water to settle for about 35 minutes, and observe its colour and smell every minutes. Test the water again for pH..
6. Tie with an elastic band the tea filter or cotton cloth round the neck and over opening of a funnel (filter bottle); the bottle that has its bottom cut off. Turn mouth end tube down into a 1000 ml collection bottle.
7. Place in the 500 g gravel stones for first layer at the bottom, the 700 g silt sand for middle layer and then the 700 g fine sand for last layer (top) into the funnel.
8. Cautiously pour about three litres of boiled tap water through the funnel, taking care not to disturb the top layer of sand. Pour the rinsed water out of the plastic bottle.
9. Pour in intermittent drops the top 2 l of muddy or grey water through the tea filter, taking care to leave the residual sediment in the marsh water bottle.
10. After the water has dripped through the filter media (fine sand, sand silt and gravel) compare the grey water or muddy water left in the 2 litre bottle to the filtered water that collected in the 1000 ml plastic bottle or large glass container. What can you say about look and smell of these samples of water?

11. Add one drop (about 0.094 ml) of regular liquid bleach to the 500 ml filtered water collected in the 1litre bottle. Mix thoroughly and allow to stand for 30 minutes. Then, smell the water. If the water has a faint smell of chlorine, it is well chlorinated. If you cannot detect any chlorine odour, add one drop of regular liquid bleach (1 drop for ½ litre bottle). Allow to stand, and smell it again. It takes 45 minutes to destroy Giardia Protozoan (common cause of diarrhea) with 1 ppm chlorine level.

### Results (Observation): What happened during the purification of water?

Draw the diagram of the water purification system demonstrated in the classroom and label it clearly, indicating the locally available materials used and the stages of water purification. (Explain your observations with the aid of a diagram.), (see 4.2.5 for observation results)

(13)

In the class discussion the researcher explained the chemistry that occurred at each stage of water purification using locally available materials. The project took learners through the five fundamental phases of water purification that are aeration, coagulation, sedimentation, filtration, and disinfection (see Figure 4, sub sections 3.8 & 4.2.5).

### Questions and suggested answers

1. Describe the appearance, smell and pH of the water before starting the process. (3)

*Dirty, dark coloured, offensive, sharp smell, universal indicator changed to light blue pH=7.5.*

2. Write down the chemical formula of alum. (3)

$Al_2(SO_4)_3 \cdot 12 H_2O$

3. Demonstrate the dissociation equations of alum in aqueous solution (dirty water) and indicate whether pH **INCREASES** or **DECREASES**. (2x3)

$Al_2(SO_4)_3 \cdot 12 H_2O (aq) \rightarrow Al^{3+} (aq) + 3SO_4^{2-} (aq) + 12 H_2O (l)$

$SO_4^{2-} (aq) + H_2O (l) \rightleftharpoons HSO_4^- (aq) + OH^- (aq)$  ( pH increases to basic)

4. Explain how metal ions are removed from water as impurities by the addition of alum. Name this chemical step in water purification. (3)

*The slightly basic water causes  $Al(OH)_3$ ,  $Fe(OH)_3$  and  $Fe(OH)_2$  to precipitate, bringing the small particulates with them and the water becomes clear. Coagulation.*

5. Name any two metal ion impurities that cause water to look coloured or dirty. (2)

*Fe<sup>3+</sup> and Cr<sup>3+</sup> (or any two coloured transition or heavy metal ions)*

6. Is alum an electrolyte or a non-electrolyte? (1)

*Electrolyte*

7. Explain why you use fine and coarse sand and small gravel in the initial stages of water purification. (3)

*To filter/remove/trap solid impurities of all sizes that do not dissolve in water.*

8. What three physical and chemical properties of filter media do you have to know before you use them? (3)

*Constant composition, uniformity, hard, insoluble in water, neutral pH*

9. Compare the appearance and the smell of the filtered water and the dirty water after percolation through the sand filter. (2)

*Dirty water has a bad, offensive smell. Filtered water has a faint smell and is colourless.*

10. The active ingredient in bleach is sodium hypochlorite (concentration 5.25–6 percent). Give the formula for bleach. (2)

*NaOCl*

11. Suggest why bleach should be “regular” and not contain soaps, perfumes or dyes when used for the disinfection of water? (3)

*Concentrations of available chlorine in bleach for killing germs become less due to reactions of these chemicals with chlorine in water, which increases chlorine demand.*

12. What do you understand by the term “1 ppm chlorine level”? Why are levels of chlorine in water measured in ppm or mg/L? (2)

*Concentration of available chlorine in water is one part per million or one milligram per litre. Since chlorine is a strong oxidising agent and disinfectant it is used in very low levels to purify water as high levels could cause health risks, even fatalities.*

13. According to EPA document, a 4546L tank of water for household use and drinking purposes needs to be disinfected once or twice a month with 150g of bleach (NaClO). Commercial bleach originally contains approximately 5.25% bleach by mass and about 0.7M; 500ml of filtered water was collected in the 1L bottle ready for disinfection with regular bleach, as described above.

Use the above information to answer the following questions:

- 26.1 What is the meaning of M? (2)

- 26.2 Find the formula mass of bleach. (2)

- 26.3 Determine the mass of bleach in mg needed to treat 500ml of filtered water you collected. (4)
- 26.4 Use the mass you determined above to calculate the number of moles of bleach in 500ml of water. (3)
- 26.5 Assuming that there was no significant chlorine demanded or lost when bleach reacted with 500ml water; determine the concentration of bleach in ppm of this water. (4)

**Grand total: 60 marks**



## **Appendix 8: Lesson 3 (Post-test, Research-Based Test 2 (RBT2))**

Subject: Grade 11 Physical Sciences

Duration: Two class periods (2 x 45 minutes)

Topic: Post-test (RBT2) on chemistry of water purification and suggested answers

### **Lesson objectives**

- 1) Learners should be able to study and understand the questions.
- 2) Learners should be able to understand chemical equations involving precipitations, redox reactions and acid-base system in order to explain the chemical concepts of water purification: aeration, coagulation and chlorination.
- 3) Learners should be able to support with physical and chemical reasons the use of appropriate LAM to remove impurities in water at each stage of water purification process.

### **Pre-activity assessment**

Discuss with learners their everyday use of water and the need to conserve this natural basic resource. Ask learners to explain how water purification can help to save water at household level and challenge them to apply classroom chemistry to make a prototype water purification device using LAM as noted earlier in lessons 1 and 2, using the attached innovative research project task (see Appendix 6)

### **Activity assessment**

The learners will be given question papers and answer the questions in the spaces provided.

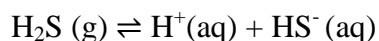
### **Activity extensions**

Learners to proceed with their innovative research project of developing a prototype device using LAM (see Appendix 6).

### **QUESTION 1**

6. What type of solutions do  $\text{Al}_2(\text{SO}_4)_3 \cdot 12\text{H}_2\text{O}_{(\text{aq})}$ , and  $\text{Ca}(\text{OH})_{2(\text{aq})}$  form when used in the process of coagulation to precipitate impurities in water during water purification?
  - A. Electrolytes✓✓
  - B. Non-electrolytes
  - C. Good electrical conductor
  - D. Ionic solids
7. Which statement best describes pH changes that occur when alum and lime are added to water to cause precipitation during coagulation?

- A. pH decreases to acidic
  - B. pH increases to acidic
  - C. pH increases to basic✓✓
  - D. pH becomes neutral
8. Precipitation of impurities in water such as metal ions takes place through coagulation. Which type of change characterises precipitation?
- A. Physical change
  - B. Chemical change✓✓
  - C. Both physical and chemical change
  - D. None of the above
9. Gases such as hydrogen sulphide and ammonia are removed as impure gases in dirty water during water purification because they
- A. Form an immiscible mixture with water
  - B. Are insoluble in water
  - C. Dissolve in water due to hydrolysis followed by hydration
  - D. Dissolve in water due to hydration followed by hydrolysis✓✓
10. Some reactions that take place during aeration are represented below:



Which two ionic species (impurities) are removed from water during aeration and in what phase are they removed?

- A. HCl and Cl<sup>-</sup> in gas phase
  - B. HS<sup>-</sup> and H in aqueous solution
  - C. HCl and H<sub>2</sub>S in gas phase✓✓
  - D. HS<sup>-</sup> and Cl in aqueous solution
11. Which species acts as an effective disinfectant in the following equation?
- $$\text{Cl}_2(\text{g}) + 2\text{H}_2\text{O (l)} \rightleftharpoons \text{HOCl (aq)} + \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})$$
- A. Cl<sub>2</sub>
  - B. HOCl✓✓
  - C. H<sub>3</sub>O<sup>+</sup>
  - D. Cl<sup>-</sup>
7. The partial hydrolysis of HOCl is best described by which chemical equation?

- A.  $\text{Cl}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HOCl}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})$
- B.  $\text{HOCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{OCl}^-(\text{aq})$  ✓✓
- C.  $\text{HOCl}(\text{aq}) + \text{OCl}^-(\text{aq}) \rightleftharpoons \text{HCl}(\text{aq}) + \text{Cl}_2(\text{g})$
- D. None of the above
8. The walls of pathogenic organisms are negatively charged. Which of the species resulting from *chlorination* of water below will effectively penetrate the cell wall?
- A.  $\text{HCl}$
- B.  $\text{H}_3\text{O}^+$
- C.  $\text{OCl}^-$
- D.  $\text{HOCl}$  ✓✓
9. The dissociation of  $\text{HOCl}$  is pH dependent and represented by the following equation:
- $$\text{HOCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{OCl}^-(\text{aq})$$
- Identify the acid–base conjugate in the above system.
- A.  $\text{HOCl}$  and  $\text{OCl}^-$  ✓✓
- B.  $\text{HOCl}$  and  $\text{H}_3\text{O}^+$
- C.  $\text{H}_2\text{O}$  and  $\text{OCl}^-$
- D.  $\text{H}_2\text{O}$  and  $\text{H}_3\text{O}^+$
10. Which pH description of water is most favourable for formation of hypochlorous acid that is a more effective disinfectant?
- A. None
- B. Neutral pH
- C. Low pH
- D. High pH ✓✓

[2]

## QUESTION 2

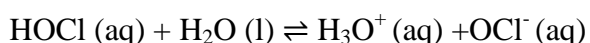
2. The equation below represents a redox system involving aeration of water, resulting in the removal of some metal ions as impurities.
- a)  $4\text{Fe}^{2+}(\text{aq}) + \text{O}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{Fe}(\text{OH})_3(\text{aq}) + 8\text{H}^+(\text{aq})$
- b)  $2\text{Mn}^{2+}(\text{aq}) + \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{MnO}_4^-(\text{aq}) + 4\text{H}^+(\text{aq})$
- 2.1 Name the chemical process responsible for removing contaminant ions in equations a) and b) above. (2)
- Precipitations of higher oxidised metal ions*

- 2.2 Identify the two ions removed from the chemical reactions represented by a) and b).  
*+3 and +7 ions for iron and manganese respectively* (2)
- 2.3 Equations a) and b) above represent a redox system.
- 2.3.1 What is meant by the term redox system? (2)  
*In chemical reactions reduction and oxidation take place simultaneously. (While one species is oxidised the other is reduced.)*
- 2.4 Explain in terms of oxidation numbers whether the following ions in the equations in 2a) and 2b) above are **OXIDISED** or **REDUCED**. (2x3)
- a)  *$Fe^{2+}$  ions: Oxidised to  $Fe^{3+}$  ions; increase in oxidation number from +2 to +3 due to loss of electrons*
- b)  *$Mn^{2+}$  ions: Oxidised to +7 ions of Mn; increase in oxidation number from +2 to +7 due to loss of electrons*

[10]

### QUESTION 3

3. Write down the chemical equation that represents chlorination of water (addition of chlorine to water ). (3)  
 $Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + H^+(aq) + Cl^-(aq)$   
*or*  
 $Cl_2(g) + 2H_2O(l) \rightleftharpoons HOCl(aq) + H_3O^+(aq) + Cl^-(aq)$
- 3.1 Use your knowledge of the periodic table of elements to indicate why chlorine is a strong oxidising agent and an effective disinfectant. (4)  
*Chlorine is highly electronegative and a very reactive gas. It reacts not only with water but with many organic and inorganic substances in water and oxidises them. Chlorine that remains after these reactions (chlorine demand) reacts with water to produce a stronger disinfectant hypochlorous acid (HOCl).*
- 3.2 Explain the type of reaction the chemical equation of which you wrote in your answer to question 3 above. This reaction involves the use of water. (2)  
*Hydration (addition of water) followed by hydrolysis of chlorine*
- 3.3 Consider the pH dependent equation below representing the dissociation of a weak acid resulting from chlorination of water into its ions.



- 3.3.1 Identify the species in the above reaction that is acting as a weak acid. Explain your answer. (3)

*HOCl. Partial dissociation and proton donor to water.*

- 3.3.2 Give chemical names for HOCl and OCl<sup>-</sup> (2)

*Hypochlorous acid and hypochlorite ion.*

- 3.3.4 Name or indicate by labelled arrows the acid-base conjugate and base-acid conjugate pairs in the above acid-base system in 3.3 above. (2x2)

*Acid-base conjugate pairs: HOCl and OCl<sup>-</sup>.*

*Base-acid conjugate pairs: H<sub>2</sub>O and H<sub>3</sub>O<sup>+</sup>*

- 3.3.5 The walls of pathogenic organisms are negatively charged. Use this chemistry concept to explain which one species, HOCl or OCl<sup>-</sup> is a stronger disinfectant. (4)

*Hypochlorous acid is more reactive and is a stronger disinfectant than hypochlorite ions. Hypochlorous acid, which is neutral, can penetrate negatively charged slime layers, cell walls and protective layers of pathogens and kill them more effectively than negatively charged hypochlorite ions, which result in repulsions.*

[22]

#### QUESTION 4

4. OCl<sup>-</sup> ions dissociate into an oxygen atom and chloride ions.

- 4.1 Write down the balanced chemical equation representing the above statement.



- 4.2 Explain why the oxygen atom is a strong oxidising agent. (2)

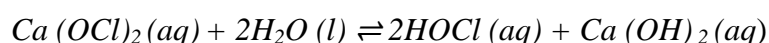
*Highly electronegative, very reactive as it easily accepts electrons and is itself reduced*

- 4.3 Which is the stronger disinfectant, the oxygen atom or chlorine? Why? (2)

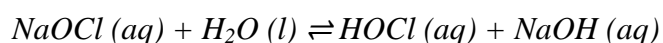
*Chlorine, being more electronegative, is a stronger oxidising agent hence more reactive with most pathogens*

- 4.4 Write down the balanced chemical equations a) and b) for the word equations representing reactions of sodium hypochlorite and calcium hypochlorite with water shown below: (2x3)

- a) Calcium hypochlorite + Water → Hypochlorous Acid + Calcium Hydroxide



- b) Sodium hypochlorite + Water → Hypochlorous Acid + Sodium Hydroxide



- 4.5 Discuss why pure chlorine is a more effective disinfectant than bleaches (calcium hypochlorite and sodium hypochlorite) (2)

*Hypochlorites are less pure than chlorine gas because they decompose (unlike pure chlorine) in storage owing to the effects of temperature, light and heat energy before they are able to react with pathogens in water.*

[14]

### QUESTION 5

5. Alum and lime in aqueous solutions are electrolytes that dissociate to yield ions, changing the pH of water.

- 5.1 What is meant by the term electrolyte? (2)

*A solution resulting from dissociation of an ionic salt into its ions, which conduct electricity and are broken down in the process.*

- 5.2 Give the chemical formulae of alum and lime. (2x2)

*Alum-  $Al_2(SO_4)_3 \cdot 12 H_2O$ ; Lime-  $Ca(OH)_2$*

- 5.3 Demonstrate the dissociation of lime into its ions in aqueous solution by means of an equation, and justify why aqueous lime is an electrolyte. (3)

*$Ca(OH)_2(aq) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$ : Because it dissociates into cat ion  $Ca^{+2}$  and anion  $OH^-$  in aqueous solution that conducts electricity.*

- 5.4 Coagulation results from the addition of alum and lime to dirty water and brings about pH changes. As dirty particles combine and are removed, the water becomes clear.

- a) Does the pH **INCREASE** or **DECREASE** when alum and lime are added to water? *INCREASES*

- b) Use this information to explain how some metal ions are removed as impurities. (2)

*The water which is slightly basic owing to addition of alum causes metal ions to precipitate, taking the small particulates with them and the water becomes clear.*

- c) Name two metal ions that are removed as impurities through a process of coagulation. (2)

*$Fe^{3+}$  and  $Al^{3+}$  ions are precipitated in their hydroxides during the processes of coagulation and flocculation. (Any other coloured, heavy metal ions in higher oxidation numbers.)*

[14]

**Grand Total=80**

## Appendix 9: Rubric Assessment Tool (RAT)<sup>13</sup>

RAT (see Appendix 5 & Appendix 6).

	Level				
	Descriptors				
Skills	A	B	C	D	Marks
Introduction	No introduction	One important	Two innovation	Research	
Contextual background of device.	or is inappropriate.	innovation	concepts related	concepts	
Research question(s), variables.	Aim and purpose of device not clear.	concept related to chemistry of water purification is stated.	to operational chemistry of water purification stated.	clearly related to chemistry of water purification	
Aim and purpose of innovation	2 marks	5 marks	7 marks	10 marks	
Literature review:	Literature focus is not related or is irrelevant to stages/chemistry of purification.	Literature is mentioned, but unrelated to the topic/research.	Literature is mentioned with little relationship to topic/research questions.	Literature is relevant and relates very well to the topic/research questions.	
Applying chemistry of water purification using LAM.	0 mark	1 marks	3 marks	4 marks	
Research Method:	No diagram, or diagram is present with inappropriate scale, no labels or arrows. No	Diagram is present with unclear/mis-placed/wrong labels, arrows. Scale is not	Diagram is clear with some correct labels and arrows in colour and in space. Good drawing skills.	Very good drawing skills clearly showing the schematic embodiment	
Design and Technology of device.					

<sup>13</sup> The rubric assessment tool (RAT) that was adapted by the researcher from the Department of Education (DoE), (2011) and University of Cape Town's (2011) Sasol School projects was specifically developed for learners' innovative project of water purification. Teachers are discouraged not to use generic rubrics for specific set tasks, particularly in formative assessments.

	LAM used.	proportional to size of design. Fair drawing skills. Some LAM used inappropriately.	LAM used appropriately.	of the device. LAM used correctly.	
	2 mark	4 marks	6 marks	8 marks	
Construction Methods	Measurements, marking out, cutting and assembling of materials to form device not done or not in proportion.	Any one of the skills measurements, marking, or cutting is to design scale and proportional.	Construction of device is to design scale in terms of measurements, space, marking out, cutting, etc.	Construction of device is to design scale in terms of measurements, space, marking out, cutting, etc.	
	2 marks	4 marks	6 marks	9 marks	
Discussion or Analysis of device: Originality and functionality.	Device appearance is not to scale (too big or too small) and not in operational mode.	Device is made to proportion, but appearance is not good in terms of size and shape.	Device has good shape and is sized to proportion, but not in working order.	Very attractive portable device made to design scale, and is manually operational.	
	1 mark	2 marks	4 marks	5 marks	
Results and conclusion: oral presentations, project write-up. Writing skills,	There are many grammatical, spelling mistakes. No references.	There are a few significant grammatical, spelling and/or scientific errors. Data recorded	There are no significant grammatical, spelling and/or scientific errors. Good manipulation of	There are no grammatical, spelling and/or scientific errors. Correct use of	



references graphs or flow charts		logically in appropriate format (e.g. correct headings, units, labels, etc.). Irrelevant references.	data (e.g. flow charts or schematic diagrams). Correct references but not used.	references.	
	1 mark	3 marks	4 marks	7 marks	
TOTAL/100					

## **Appendix 10: Letter of request to conduct research in schools**

Cell: 071-005-1616

Shingwedzi High School

P/Bag X9156

Malamulele

0982. Limpopo Province.

**13 June 2011.**

The Circuit Manager

Department of Education

Malamulele Central Circuit

**Malamulele, 0982.**

Dear Sir,

### **RE: PERMISSION TO CARRY OUT RESEARCH IN YOUR SCHOOLS.**

I am **ROBERT DAVISON MAKONI** registered student with UNISA, Student number 48728575, studying **Master of Science in Mathematics, Science and Technology Education** (with specialisation in Chemistry Education) in University of South Africa.

As part of the degree programme on my chosen topic: **TEACHING CHEMISTRY OF WATER PURIFICATION IN GRADE 11 USING LOCALLY AVAILABLE MATERIALS THROUGH THE SCIENTIFIC INQUIRY APPROACH**, it requires that I interview, and administer questionnaires and written activities and tests to Grade 11 Physical Sciences learners, in addition to teaching and accessing the school laboratory. The topic also requires that I interview teachers, who in turn will be teaching the research topic during intact classes.

I, therefore request permission to work with Physical Sciences teachers and learners for the period July- December, 2011. The four schools that I have randomly selected are:

1. A
2. B
3. C

4. D

The contact details of my UNISA Supervisor/ Project leader are:

Professor H.I. Atagana- 012-429-3903

The participants will enter the research process on voluntary basis and will give consent to being participant in writing. The privacy of the participants will be ensured through anonymity and confidentiality. The research proposal will be made very clear to all participants, all parties hereinafter called participants for the benefit of the local schools in particular, and the country will share the findings thereof in general.


Looking forward to hearing from you soon.

Thanking you for your co-operation.

Yours Faithfully,

Robert D. Makoni.

## Appendix 11: Letter of permission to conduct research

	<b>Limpopo</b> <b>PROVINCIAL GOVERNMENT</b> REPUBLIC OF SOUTH AFRICA DEPARTMENT OF EDUCATION <b>VHEMBE DISTRICT</b> <b>MALAMULELE CENTRAL CIRCUIT</b>	Private Bag X 9133 Malamulele 0982 Tel: (015) 851 0381 Fax : (015) 851 0035
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Ref: 82943419 Eng: Hlungwane R.M. Cell: 084 230 5572	20 June 2011
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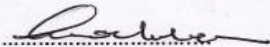
  

The Principal  
Shingwedzi High School  
Private bag x 9156  
Malamulele  
0982

**PERMISSION TO CONDUCT RESEARCH IN LOCAL SCHOOLS: MAKONI R.D.**

1. The above matter refers.
2. Permission is hereby granted for the above mentioned educator to conduct a research in our local schools, as long as it does not affect the effective learning and teaching.
3. We always appreciate your co-operation.

 CIRCUIT MANAGER	<table border="1" style="width: 100%;"><tr><td><b>Malamulele Central Circuit</b> Department of Education</td></tr><tr><td style="text-align: center;">22 JUN 2011</td></tr><tr><td>Telefax: (015) 851 0035 P/Bag X 9133 Malamulele 0982</td></tr><tr><td><b>LIMPOPO PROVINCE</b></td></tr></table>	<b>Malamulele Central Circuit</b> Department of Education	22 JUN 2011	Telefax: (015) 851 0035 P/Bag X 9133 Malamulele 0982	<b>LIMPOPO PROVINCE</b>
<b>Malamulele Central Circuit</b> Department of Education					
22 JUN 2011					
Telefax: (015) 851 0035 P/Bag X 9133 Malamulele 0982					
<b>LIMPOPO PROVINCE</b>					

## Appendix 12: Parent/guardian consent form

### Guardian Agreement for Participation of Child in the Research.

I, \_\_\_\_\_ ID no: \_\_\_\_\_ contact  
no: \_\_\_\_\_ being the parent/guardian of \_\_\_\_\_  
(name of learner if under 18 years), do hereby grant consent voluntarily to my child  
hereinafter called \_\_\_\_\_ (name of child), doing grade \_\_\_\_\_  
at \_\_\_\_\_ School, Malamulele Central Circuit, Vhembe District, to  
participate in the research which will be conducted by Mr Robert Davison Makoni, registered  
UNISA student-researcher, and also Physical Sciences teacher based at Shingwedzi High  
School, Malamulele Central Circuit, Vhembe District in Limpopo Province.

The title of the research is: **TEACHING CHEMISTRY OF WATER PURIFICATION IN  
GRADE 11 USING LOCALLY AVAILABLE MATERIALS THROUGH SCIENTIFIC  
INQUIRY APPROACH.**

As per UNISA's **Code of Conduct for Research**, the following conditions apply: the  
participants will enter the research process on a voluntary basis and will give consent to being  
a participant in writing. The privacy of the participants will be ensured through anonymity  
and confidentiality. The research proposal will be made very clear to all participants and the  
findings thereof will be shared by all parties hereinafter called participants for the benefit of  
the local community in particular and the country in general. The participants will be  
informed about how the data they provide will be utilised. Participants may withdraw from  
the research at any time.

The contact details of my UNISA Supervisor/Project leader are:

1 Professor H.I. Atagana- 012-429-3903

#### **Declaration:**

Signature of

Parent: \_\_\_\_\_ Place \_\_\_\_\_ Date \_\_\_\_\_

Researcher \_\_\_\_\_ Place \_\_\_\_\_ Date \_\_\_\_\_

## Appendix 13: Participant declaration/consent form

### Participant Consent Declaration

I, \_\_\_\_\_ ID  
no: \_\_\_\_\_ contact no: \_\_\_\_\_ based at  
\_\_\_\_\_ (name of institution) job/profession) do hereby agree voluntarily to  
participate in the research being conducted by Mr Robert Davison Makoni, registered UNISA  
student-researcher, and also Physical Sciences Teacher based at Shingwedzi High School,  
Malamulele Central, Vhembe District in Limpopo Province. Cell: 071 0051616.

The title of the research is: **TEACHING CHEMISTRY OF WATER PURIFICATION IN  
GRADE 11 USING LOCALLY AVAILABLE MATERIALS THROUGH SCIENTIFIC  
INQUIRY APPROACH**

As per UNISA's **Code of Conduct for Research** the following conditions apply:

The participants will enter the research process on a voluntary basis and will give consent to  
being participants in writing. The privacy of the participants will be ensured through  
anonymity and confidentiality. The research proposal will be made very clear to all  
participants and the findings thereof will be shared by all parties hereinafter called  
participants for the benefit of the local community in particular and the country in general.  
The participants will be informed about how the data they provide will be utilised.  
Participants may withdraw from the research at any time.

The contact details of my UNISA Supervisor/Project leader are:

Professor H.I. Atagana- 012-429-3903

### **Declaration:**

Signature of

Participant: \_\_\_\_\_ Place \_\_\_\_\_ Date \_\_\_\_\_

Researcher \_\_\_\_\_ Place \_\_\_\_\_ Date \_\_\_\_\_

## Appendix 14: Letter of ethical clearance for research



Ref: 2011/ISTE/025

14 February, 2012

Mr. **Robert Davison Makoni**  
ISTE  
UNISA.

Dear Mr. Robert,

**REQUEST FOR ETHICAL CLEARANCE: "TEACHING GRADE 10 PHYSICAL SCIENCES USING LOCALLY AVAILABLE MATERIALS: A CASE OF WATER RECYCLING AT HOUSEHOLD LEVEL."**

Your application for ethical clearance of the above study was considered by the ISTE sub-committee on behalf of the Unisa Research Ethics Review Committee on 26 January, 2012.

After careful consideration the details and implications of the study, your application was therefore **approved** and hence you can continue with the study at this stage.

**Congratulations.**


**C E OCHONOGOR**  
**CHAIR: ISTE SUB-COMMITTEE**

**CC. PROF L. LABUSCHAGNE**  
**EXECUTIVE DIRECTOR: RESEARCH**

**PROF M N SLABBERT**  
**CHAIR- UREC.**



## Appendix: 15 Proof of submission of dissertation for Turnitin Originality Check



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File size:	<b>5.47M</b>
Page count:	<b>241</b>
Word count:	<b>66,070</b>
Character count:	<b>374,218</b>
Submission date:	<b>18-May-2015 01:00PM</b>
Submission ID:	<b>455194625</b>

THE FIRST PAGE OF YOUR SUBMISSIONS IS DISPLAYED BELOW.

TEACHING CHEMISTRY OF WATER

CHAPTER ONE

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1.1 BACKGROUND

1.2 STATEMENT OF THE PROBLEM

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